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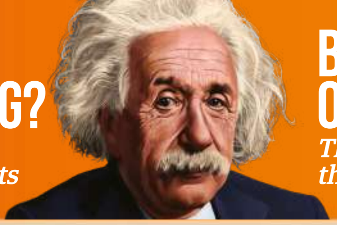

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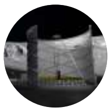
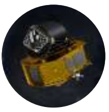


The future tech that'll see us observe from a base outside Earth **24**

Peeking inside exoplanets



Meet Ariel, a new mission to assist with studying alien world atmospheres **30**

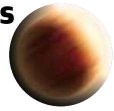
Testing Einstein

Can we break the great scientist's theory outside of the Milky Way? **42**

New view of our galaxy

Meet the Milky Way all over again, with brand-new research results **50**

Yellow alien skies



Why does the super-hot WASP-79b have an odd-coloured sky? **64**

It's all about the Red Planet as we start off 2021 - several missions will arrive at the fourth planet from the Sun this year. In early February the Emirati Hope orbiter will reach Mars, ready to study the Martian atmosphere up close, and the following day China's Tianwen-1 will arrive, preparing to deploy a rover onto the surface. NASA will be ready for action on 18 February, dropping its new Perseverance rover into Jezero crater to seek signs of extinct life on the dried-out lake and riverbed. Perseverance will also unleash Ingenuity, a little helicopter that will allow humanity to try out flight on the surface of the Red Planet for the very first time - it'll be our eyes as it scouts for areas of interest, also chartering the driving route for future rovers. Head to page 14 for our full feature on Mars.

Elsewhere in the magazine, our panel of experts answer your space questions, we investigate another mystery of the universe by examining the skies of exoplanet WASP-79b, get up close to the 'Dog Star' Sirius - you can find it in Canis Major in the evenings through to mid-spring in the Northern Hemisphere and in July if you're in the Southern Hemisphere - meet the next exoplanet surveyor and more. Our night sky guide is also packed with the latest advice on observing, plus don't forget to claim your free sky maps. Enjoy the issue!

GEMMA LAVENDER

EDITOR-IN-CHIEF

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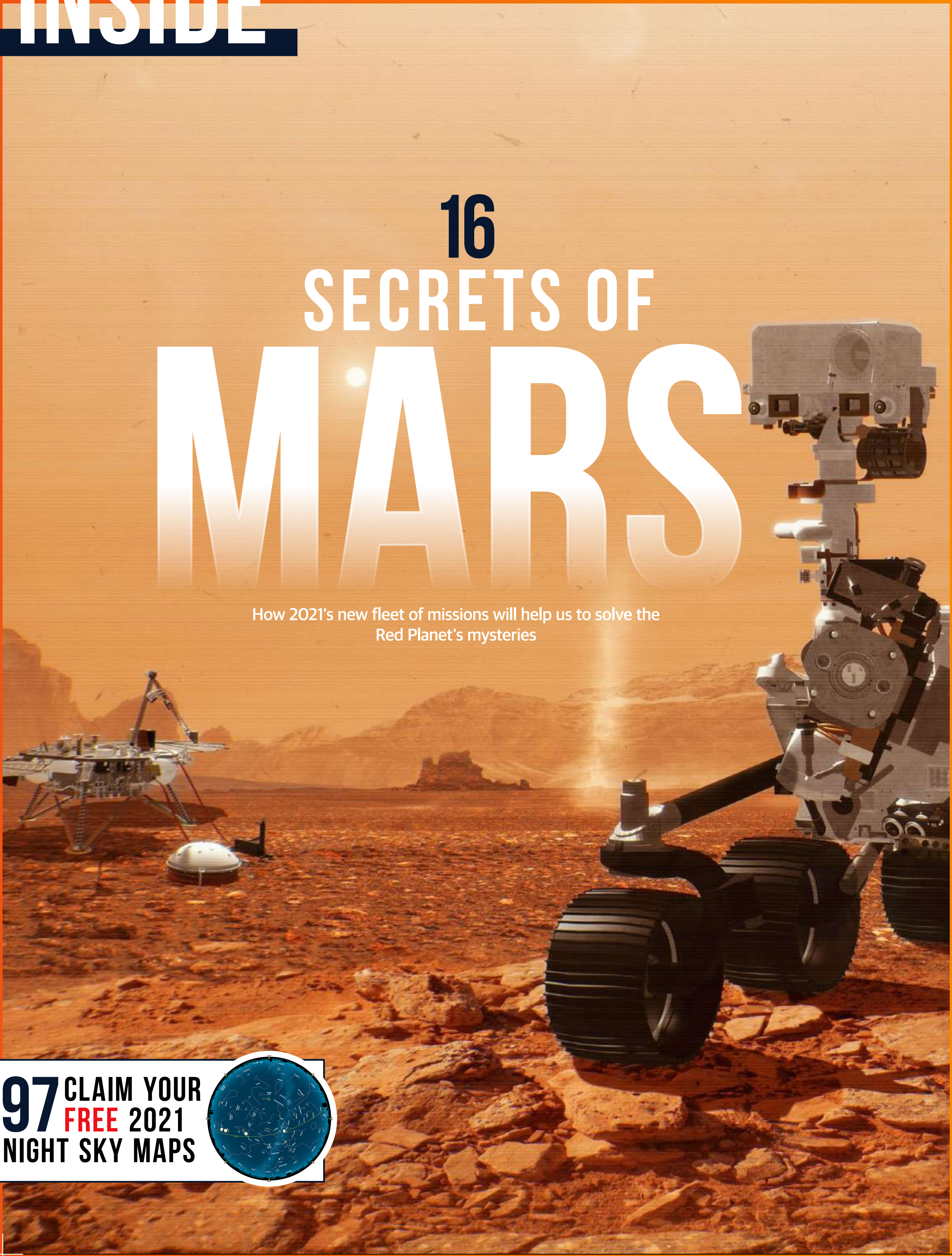
SECRETS OF MARS



16

SECRETS OF MARS

How 2021's new fleet of missions will help us to solve the Red Planet's mysteries

97 CLAIM YOUR FREE 2021 NIGHT SKY MAPS

INSIDE

LAUNCHPAD

06 News from around the universe
Planetary protection needs to be kicked up a notch, our galaxy could be full of dead civilisations and a supermassive black hole keeps evading detection

FUTURE TECH

24 Ultimately Large Telescope on the Moon
With a large enough instrument, we could look into space from another world

INTERVIEW

26 Becky Smethurst
All About Space talks to the astrophysicist and YouTube sensation about life, the universe and everything

30 Rise of the exoplanet explorer
How the next generation of alien-world hunters will help us to gain an understanding of them and their atmospheres

STAR PROFILE

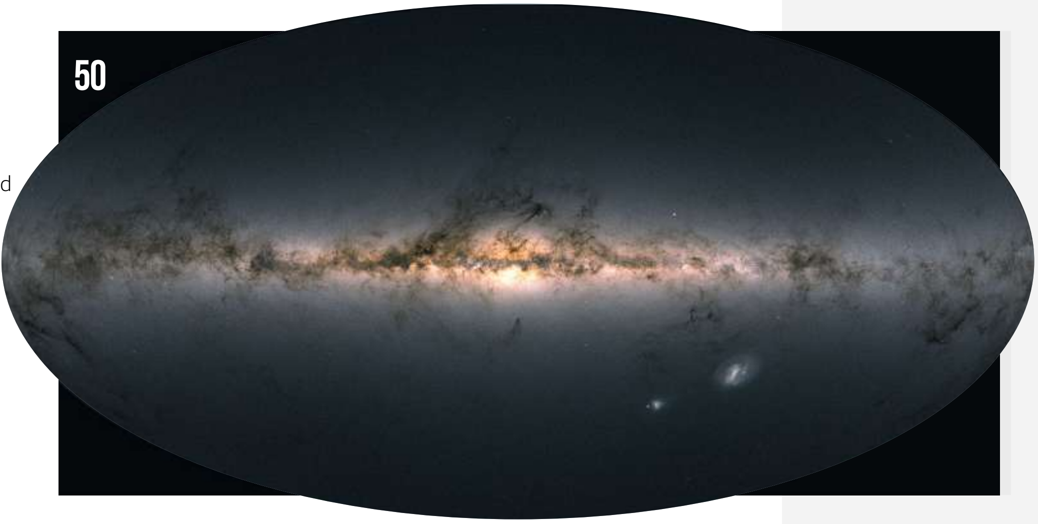
36 Sirius
The 'Dog Star' hasn't been around for very long in cosmic terms

42 Testing Einstein
Can the great scientist's theory of general relativity be pushed beyond its limits outside the Milky Way?

INSTANT EXPERT

48 What is the Fermi Paradox?
If planets are so commonplace throughout the universe, where are all the aliens?

50 A new view of the Milky Way
A dynamic, complicated, bubble-blowing wild child: meet our galaxy all over again



> *"Space is the ideal laboratory for testing general relativity"*

FOCUS ON

56 Five-hundred-meter Aperture Telescope
Following the collapse of Arecibo, China has made FAST available to international scientists

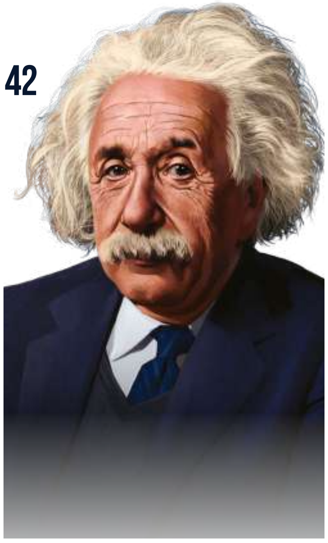
58 Brown dwarfs
The strange celestial objects that don't make the cut as either planets or stars

64 Strange yellow skies of a hot Jupiter
Astronomers are attempting to discover why WASP-79b has an odd-coloured sky

MOON PROFILE

70 Charon
The secrets and history of Pluto's largest moon

74 Ask Space
Your questions answered by our panel of experts



STARGAZER

78 What's in the sky?
82 Month's planets
84 Moon tour
85 Naked eye & binocular targets
86 Deep sky challenge
88 The Northern Hemisphere
90 Astroshots
92 Telescope review
94 In the shops

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New view of the Hunter's nebula

Looking like a vivid oil painting, this composite image shows an enormous cloud of gas and dust some 1,500 light years from Earth. You can see hydrogen, sulphur and hydrocarbons swirling around hundreds of young yet large stars in the Orion Nebula due to strong stellar winds. The effect appears to pepper this part of the Milky Way with gorgeous speckles of light.

The image was captured by two telescopes. Hubble picked up gases that have been heated and ionised by ultraviolet radiation from four massive stars called the Trapezium that are 100,000-times brighter than our Sun. The infrared view of the Spitzer Space Telescope exposed the carbon-rich molecules. Put together, these phenomena result in an amazing feast for the eyes.

Crystals on the Space Station

NASA astronaut Shannon Walker is currently spending 210 days on board the International Space Station (ISS), having launched on 15 November last year. She will next take command of Expedition 65, becoming only the third woman to hold the position.

Here she is pictured setting up hardware inside the Microgravity Science Glovebox (MSG). This is for an experiment called Solidification Using a Baffle in Sealed Ampoules (SUBSA). This experiment aims to crystallise melts in microgravity so that more can be understood about the process of semiconductor

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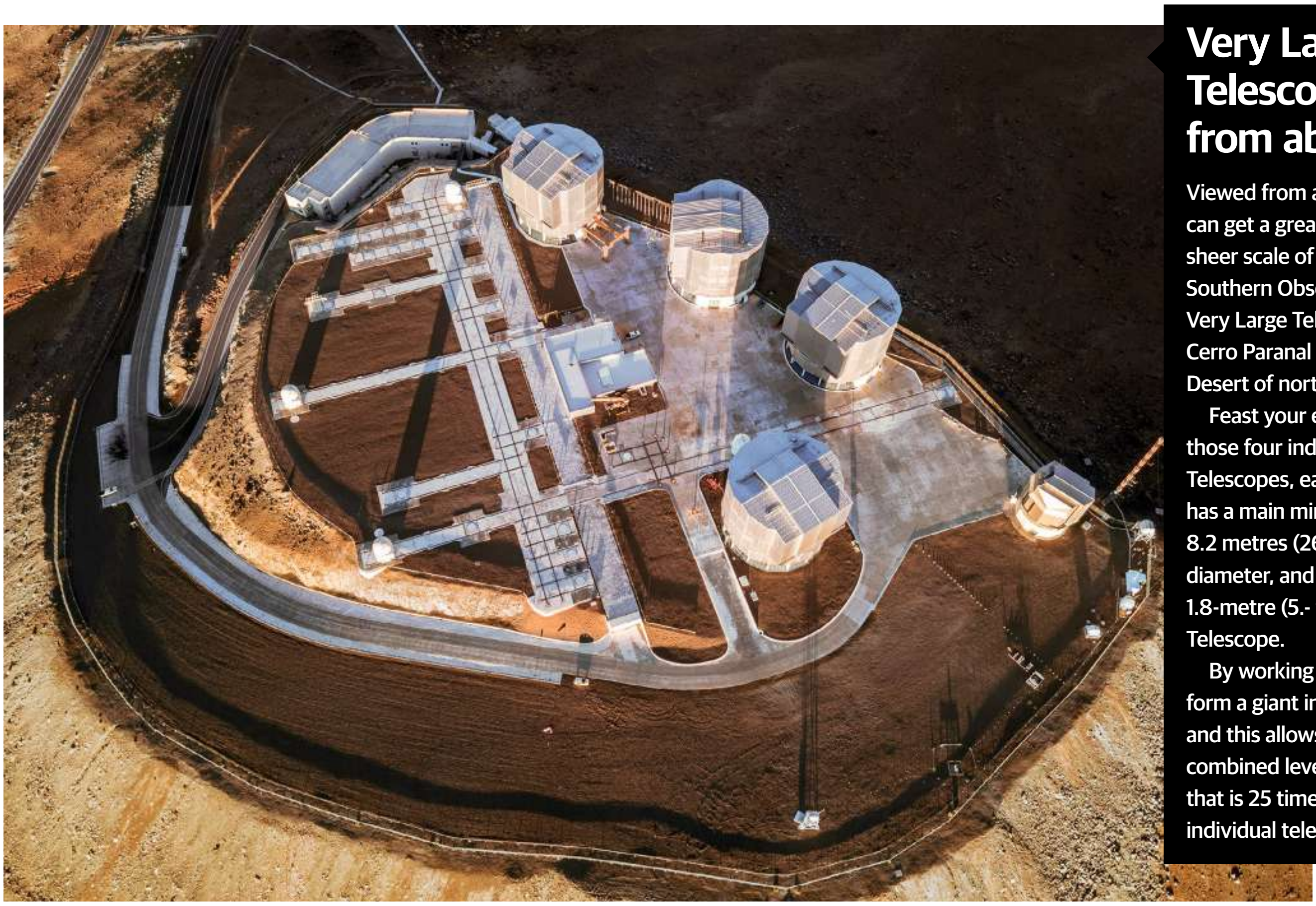

Very Large Telescope from above

Viewed from above, you can get a great sense of the sheer scale of the European Southern Observatory's Very Large Telescope on Cerro Paranal in the Atacama Desert of northern Chile.

Feast your eyes on those four individual Unit Telescopes, each of which has a main mirror that is 8.2 metres (26.9 feet) in diameter, and a movable 1.8-metre (5.- foot) Auxiliary Telescope.

By working together they form a giant interferometer, and this allows for a combined level of detail that is 25 times that of each individual telescope.

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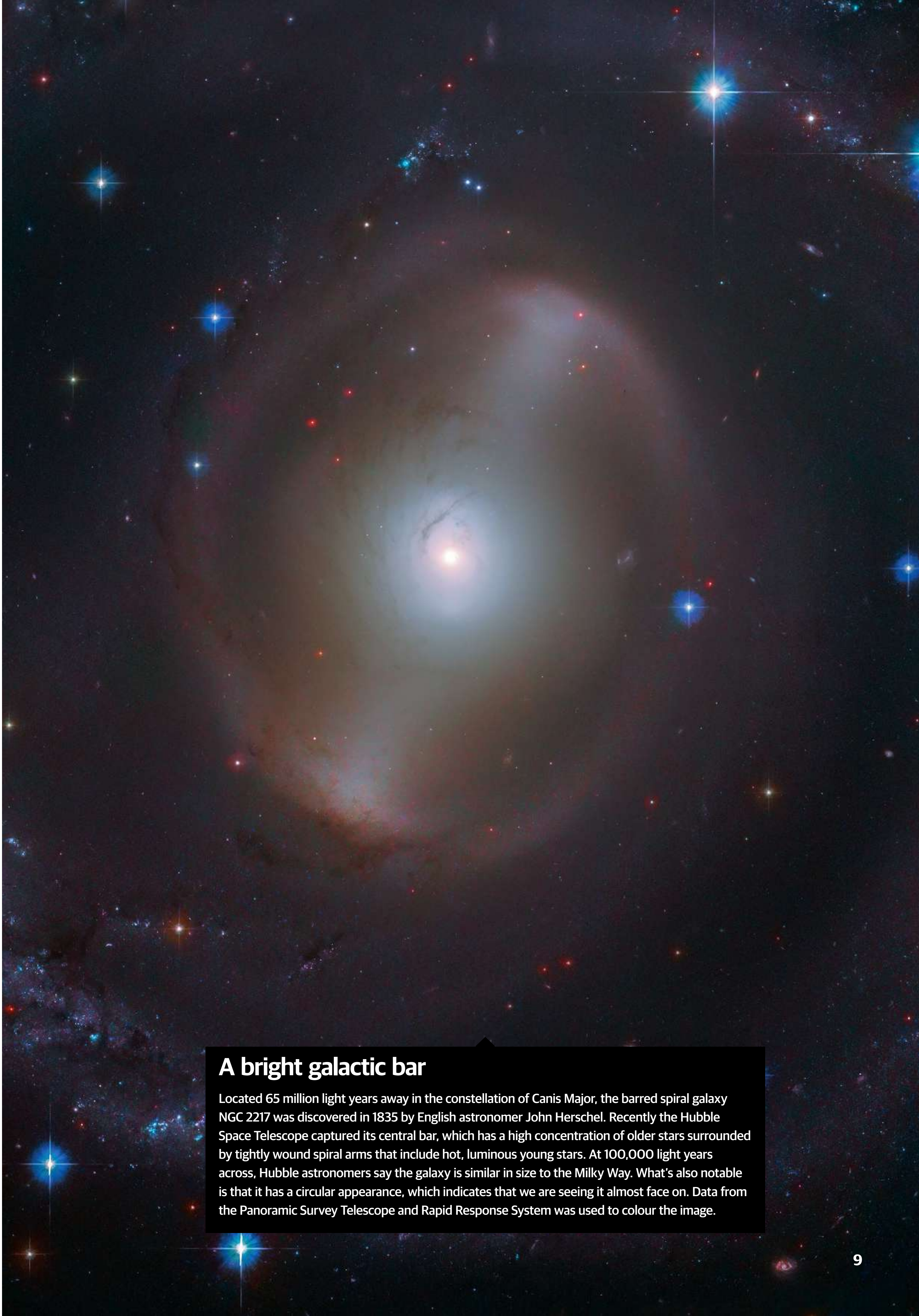

A bright galactic bar

Located 65 million light years away in the constellation of Canis Major, the barred spiral galaxy NGC 2217 was discovered in 1835 by English astronomer John Herschel. Recently the Hubble Space Telescope captured its central bar, which has a high concentration of older stars surrounded by tightly wound spiral arms that include hot, luminous young stars. At 100,000 light years across, Hubble astronomers say the galaxy is similar in size to the Milky Way. What's also notable is that it has a circular appearance, which indicates that we are seeing it almost face on. Data from the Panoramic Survey Telescope and Rapid Response System was used to colour the image.

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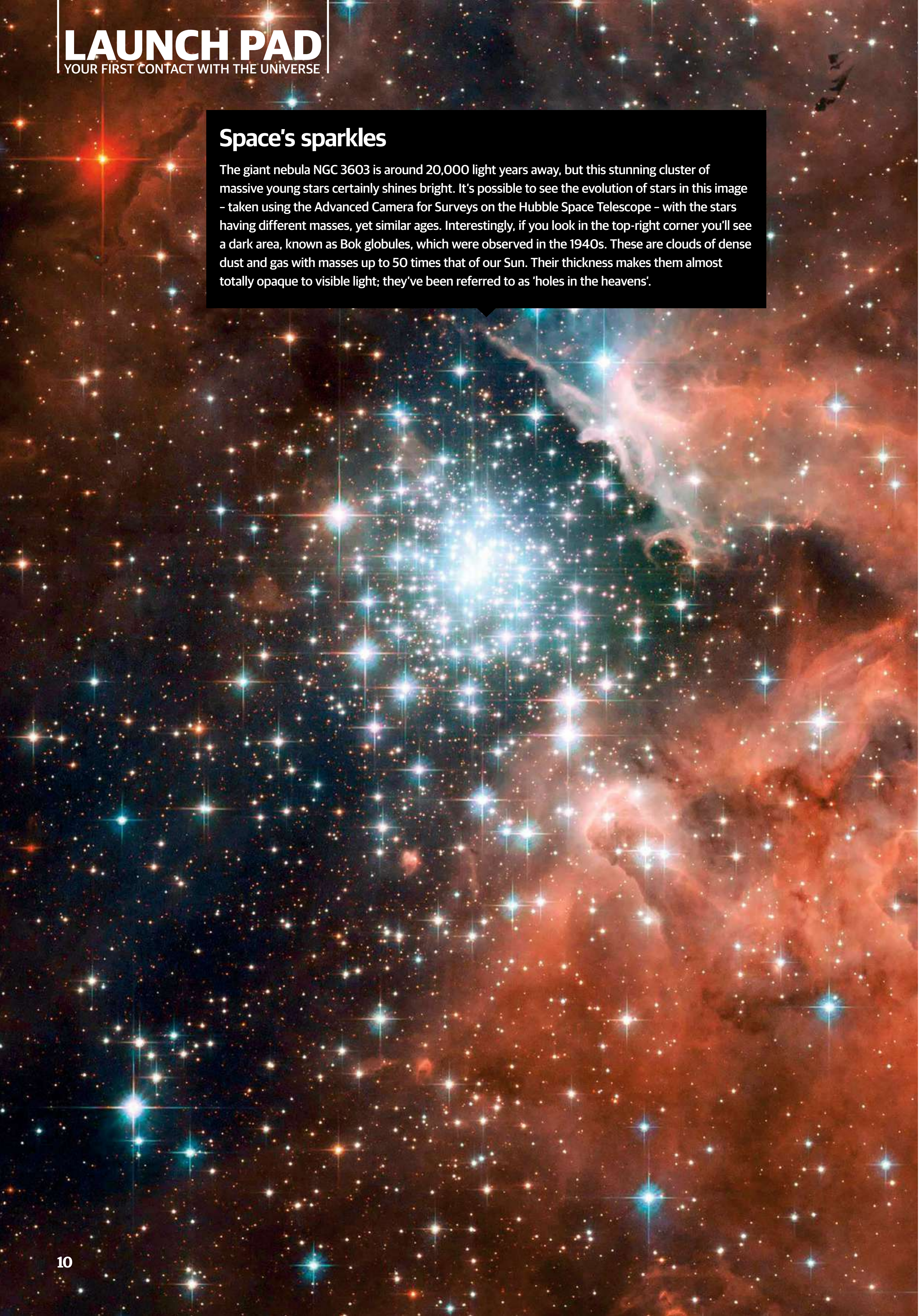

Space's sparkles

The giant nebula NGC 3603 is around 20,000 light years away, but this stunning cluster of massive young stars certainly shines bright. It's possible to see the evolution of stars in this image – taken using the Advanced Camera for Surveys on the Hubble Space Telescope – with the stars having different masses, yet similar ages. Interestingly, if you look in the top-right corner you'll see a dark area, known as Bok globules, which were observed in the 1940s. These are clouds of dense dust and gas with masses up to 50 times that of our Sun. Their thickness makes them almost totally opaque to visible light; they've been referred to as 'holes in the heavens'.

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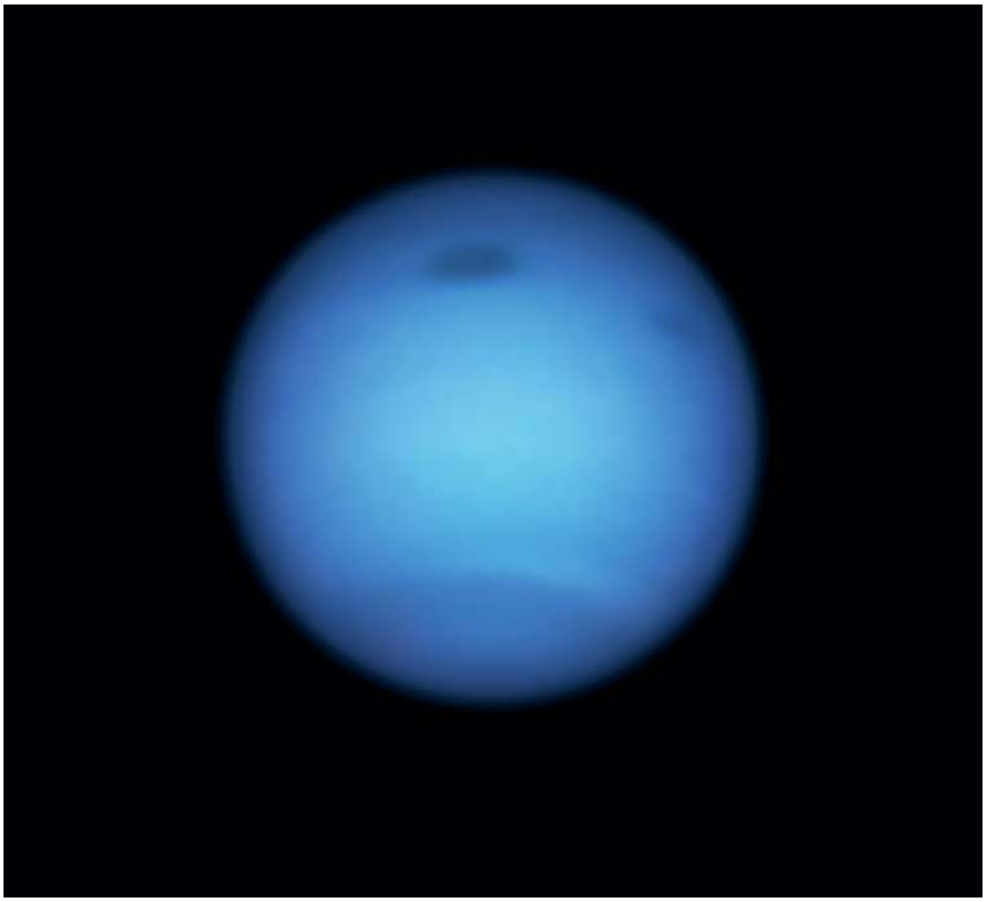

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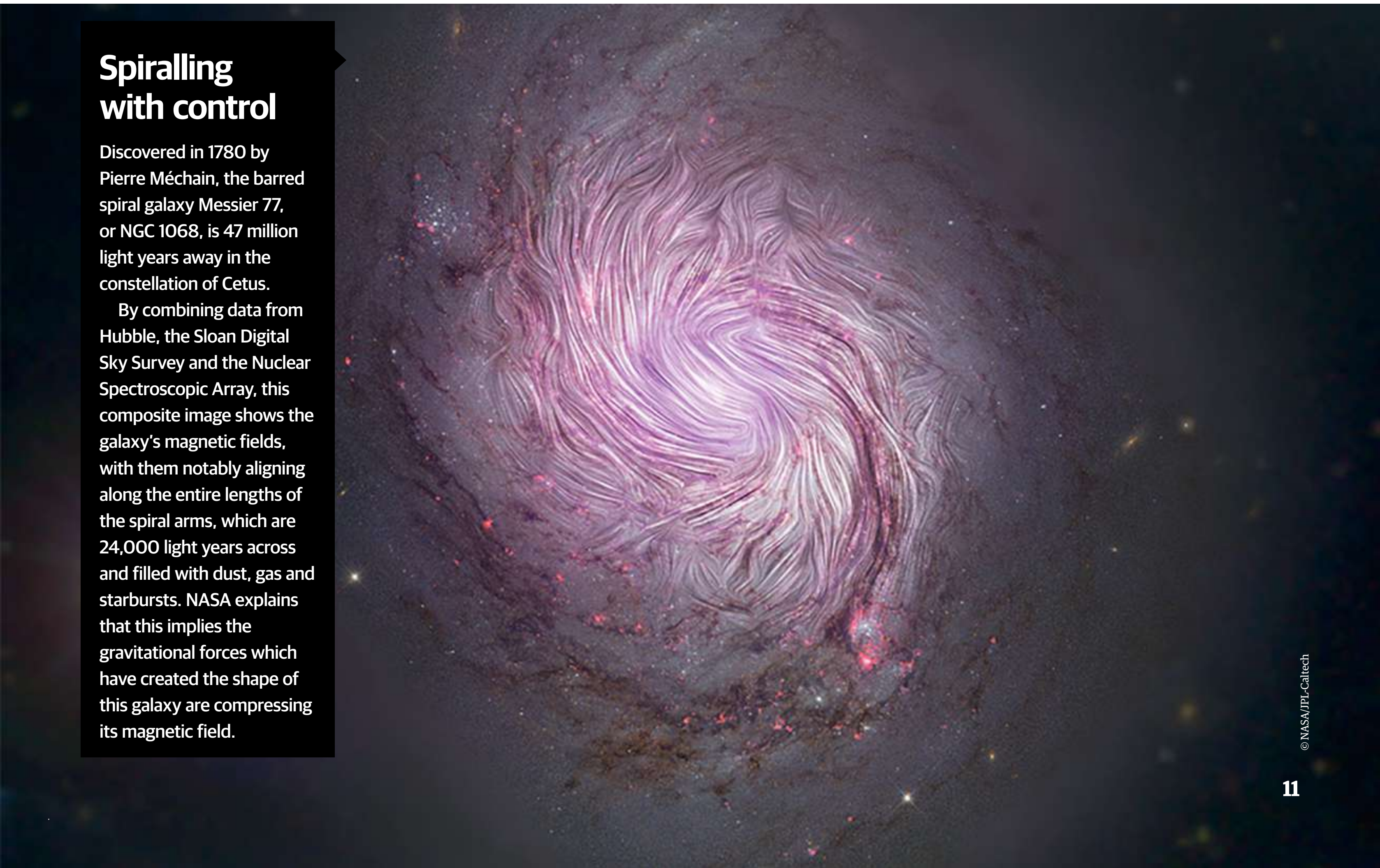
Dark storms of Neptune

Look at the dark spot on Neptune, then look to the right. You'll see another, but this one is more unusual. It was identified as a storm in 2018, and it's 7,400 kilometres (4,600 miles) across. Over the past couple of years it has been on the move, having drifted southward towards the equator before changing direction in August last year and heading back north.

Usually storms heading for the equator end up vanishing, but it's not the first time such a storm has been noted on Neptune. Voyager 2 made a flyby of the planet in 1989, and it also noted a storm moving south then back north.



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Spiralling with control

Discovered in 1780 by Pierre Méchain, the barred spiral galaxy Messier 77, or NGC 1068, is 47 million light years away in the constellation of Cetus.

By combining data from Hubble, the Sloan Digital Sky Survey and the Nuclear Spectroscopic Array, this composite image shows the galaxy's magnetic fields, with them notably aligning along the entire lengths of the spiral arms, which are 24,000 light years across and filled with dust, gas and starbursts. NASA explains that this implies the gravitational forces which have created the shape of this galaxy are compressing its magnetic field.

Planetary protection needs more than just NASA, White House plan says

Words by Meghan Bartels

The White House has laid out a plan for overhauling the federal government's planetary-protection rules, which work to prevent contamination between Earth and other potentially habitable worlds. The document outlines the government's plan for a suite of federal agencies to modernise planetary-protection rules over the course of the next year. Scientists and engineers discuss planetary protection in two directions: keeping other destinations free of Earth contamination and keeping our planet safe from potentially dangerous extraterrestrial materials. The plan is careful to note that in both directions the government must consider both its own activities and those of commercial companies.

"Current and future missions to Mars and other destinations necessitate a strategy to support a safe, sustainable and predictable Earth and space environment," Scott Pace, former executive secretary of the National Space Council and deputy assistant to Donald Trump, said in a statement released on 30 December.

The new plan builds on a goal included in a Space Policy Directive the Trump administration issued in December. "By establishing objectives for the implementation of the 2020 National Space Policy's direction on planetary protection, this strategy continues American leadership in scientific discovery, human exploration and private-sector space activities," Pace said.

Developing the strategy fell – and implementing it will fall – to the Planetary Protection Interagency Working Group established in July, which brings together nearly 20 federal agencies, of which NASA is only one. Others include the departments of agriculture, homeland security, transportation and defense, as well as the Centers for Disease Control and Prevention, the Environmental Protection Agency, the FBI and the Federal Emergency Management Agency (FEMA).

Such collaboration on issues of potentially planet-wide concern has precedent. During preparations for the Apollo 11 Moon-landing mission, which would return lunar rocks to Earth for the first time ever, public health officials in particular were instrumental in developing processes to assess the safety of astronauts and samples alike upon landing back home. Similarly, FEMA is a key partner when NASA studies issues surrounding potential impacts of nearby asteroids.

In the new strategy document, the working group highlights the age of existing planetary-protection guidelines and the changing nature of spaceflight as motivations for new procedures. For example, the report cites ongoing work to bring back samples from Mars, NASA's long-term goal of sending humans to the Red Planet and the general prevalence of commercial space players.

Some of these trends may intersect; SpaceX has touted its plans to land humans on Mars, targeting an ambitious timeline that could move faster than NASA's. Whether crewed or robotic missions, the government wants to prepare for an expected boom in commercial space launches beyond Earth orbit.

"THE GOVERNMENT MUST CONSIDER BOTH ITS OWN ACTIVITIES AND THOSE OF COMMERCIAL COMPANIES"

© NASA

Left: Many organisations are coming together to update rules that keep us – and other bodies – safe

Right (top): We might be one of the younger civilisations in the Milky Way

Right (bottom): Amphibole was found in a meteorite in Sudan

The Milky Way is probably full of dead civilisations

Words by Rafi Letzter

Most of the alien civilisations that ever dotted our galaxy have probably killed themselves off already. That's the takeaway of a new study, which used modern astronomy and statistical modelling to map the emergence and death of intelligent life in time and space across the Milky Way. The results amount to a more precise update of a famous equation that Frank Drake wrote in 1961. The Drake equation relied on a number of mystery variables – like the prevalence of planets in the universe.

The research says where and when life is most likely to occur in the Milky Way, and identifies the most important factor affecting its prevalence: intelligent creatures' tendency towards self-annihilation. The authors looked at a range of factors presumed to influence the development of intelligent life, such as the prevalence of Sun-like stars harbouring Earth-like planets; the frequency of deadly, radiation-blasting supernovae; the probability of and time necessary for intelligent life to evolve if conditions are right and the possible tendency of advanced civilisations to destroy themselves.

Modelling the evolution of the Milky Way over time with those factors in mind, they found that the probability of life emerging based on known factors peaked about 13,000 light years from the galactic centre and 8 billion years after the galaxy formed. Earth is about 25,000 light years from the galactic centre, and human civilisation arose on the planet's surface about 13.5 billion years after the Milky Way formed – though simple life emerged soon after the planet formed. We're likely a frontier civilisation in terms of galactic geography, and relative latecomers to the self-aware inhabitant scene.

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Mysterious meteoroid-spitting asteroid found in Solar System

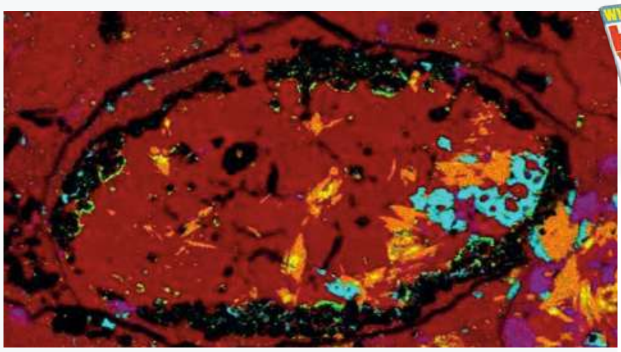
Words by Rafi Letzter

There's a giant asteroid somewhere out in the Solar System, and it hurled a big rock at Earth. The evidence for this mystery space rock comes from a diamond-studded meteor that exploded over Sudan in 2008. NASA spotted the meteor heading towards the planet well before impact, and researchers showed up in the Sudanese desert to collect an unusually rich haul of remains. New research of one of those meteorites suggests that the meteor may have broken off a giant asteroid – one more or less the size of the dwarf planet Ceres, the largest object in the asteroid belt.

Like about 4.6 per cent of meteorites on Earth, this one – known as Almahata Sitta (AhS) – is made of a material known as carbonaceous chondrite. These black rocks contain organic compounds as well as a variety of minerals and water.

The mineral make-up of these space rocks offers clues about the 'parent asteroid' that birthed a given meteor. "Some of these meteorites are dominated by minerals providing evidence for exposure to water at low temperatures and pressures," Vicky Hamilton, a planetary geologist at the Southwest Research Institute in Boulder, Colorado, said. "The composition of other meteorites points to heating in the absence of water."

The team analysed a 50-milligram sample of AhS under a microscope and found it had a unique mineral make-up The meteorite harboured an unusual suite of minerals. One mineral in particular, amphibole – often found on Earth – also requires prolonged exposure to water to develop.



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Giant black hole keeps evading detection

Words by Mike Wall

An enormous black hole keeps slipping through astronomers' nets. The big galaxy at the core of the cluster Abell 2261, which lies about 2.7 billion light years from Earth, should have an even larger central black hole – a light-gobbling monster that weighs as much as 3 billion to 100 billion Suns, astronomers estimate from the galaxy's mass. But the exotic object has evaded detection so far.

A new study has conducted an even deeper search for X-rays in the same galaxy, using Chandra observations from 2018. And this new effort didn't just look in the galaxy's centre; it also considered the possibility that the black hole was knocked away after a monster galactic merger.

When black holes and other massive objects collide, they throw off ripples in space-time known as gravitational waves. If the emitted waves aren't symmetrical in all directions, they could end up pushing the merged supermassive black hole away from the centre of the newly enlarged galaxy.

Such 'recoiling' black holes are purely hypothetical. Indeed, it is not known whether supermassive black holes even get close enough to each other to produce gravitational waves and merge. So far astronomers have only verified the mergers of much smaller black holes.

Abell 2261's central galaxy is a good place to hunt for such a unicorn. A team led by Kayhan Gultekin from the University of Michigan found that the densest concentrations of hot gas were not in the galaxy's central regions. But the Chandra data didn't reveal any significant X-ray sources, either in the galactic core or in big clumps of stars farther afield. The mystery of the missing black hole persists.

© NASA

Above: Scientists will keep searching for the hidden black hole in Abell 2261

Neptune's dark storm reverses direction

Words by Kasandra Brabaw

A dark storm on Neptune abruptly switched directions and started moving away from almost certain death, puzzling astronomers. Hubble first spotted the vortex in 2018. A year later the storm began drifting southward towards Neptune's equator, following the path of several storms before it. Usually these dark spots on Neptune live for a few years before either vanishing or fading away. However, the storm mysteriously stopped moving south and made a sharp U-turn, drifting back northwards. At the same time, astronomers spotted a second, smaller dark spot on the planet.

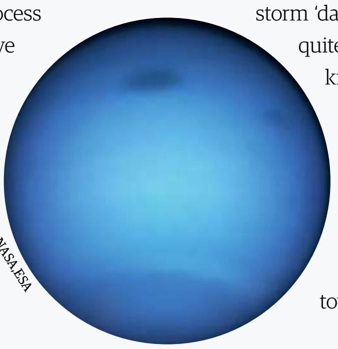
They theorise that this smaller 'cousin' storm may be a piece of the original vortex that broke off and drifted away. "We are excited about these observations because this smaller dark fragment is potentially part of the dark spot's disruption process," said Michael H. Wong of the University of California at Berkeley. "This is a process that's never been observed. We have seen some other dark spots fading away and they're gone, but we've never seen anything disrupt, even though it's predicted in computer simulations."

Although Hubble has tracked similar storms on Neptune over the past 30 years, astronomers have never seen such unpredictable atmospheric behaviour. The current storm, which is 7,403 kilometres (4,600 miles) across, is the fourth-darkest spot Hubble has tracked since 1993. These storms are high-pressure systems that rotate clockwise due to the planet's rotation, unlike hurricanes on Earth, which are low-pressure systems that rotate counterclockwise.

Typically, as storms drift towards Neptune's equator, the Coriolis effect that keeps them stable starts to weaken and the storm disintegrates. However, unlike past observed storms and computer simulations that show storms following a more or less straight path to the equator, this latest vortex didn't migrate into this 'kill zone'.

Spotting a smaller storm that potentially broke off from the larger vortex was also surprising. Astronomers are informally calling this smaller storm 'dark spot junior'. This junior is still quite large, however, stretching 6,276 kilometres (3,900 miles) across.

Although researchers can't prove that the smaller storm broke off from the larger one, Wong said, it's possible that shedding that fragment was enough to stop the larger storm from continuing on towards the equator.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Left: The faint smaller storm can be seen on the right limb of Neptune

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Scientists spot farthest galaxy yet

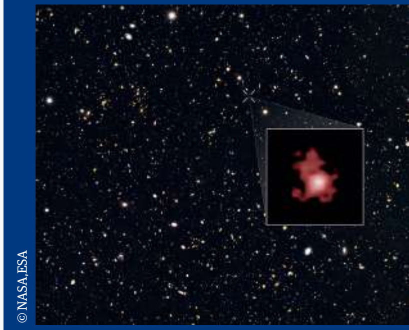
Words by Chelsea Gohd

Astronomers led by Nobunari Kashikawa, a professor in the department of astronomy at the University of Tokyo, have peered out into the vast expanse and spotted what they think is the farthest – and the oldest – galaxy ever observed.

"From previous studies, the galaxy GN-z11 seems to be the farthest detectable galaxy from us, at 13.4 billion light years, or 134 nonillion kilometres [83 nonillion miles]" said Kashikawa. "But measuring and verifying such a distance is not an easy task."

To determine how far GN-z11 is from us here on planet Earth, Kashikawa's team studied the galaxy's redshift – how much its light has stretched out, or shifted towards the red end of the spectrum. In general, the farther away a cosmic object is from us on Earth, the more redshifted its light will be.

Additionally, the team looked at GN-z11's emission lines – observable, chemical signatures in the light coming from cosmic objects. By studying these signatures closely, the team was able to figure out how far the light coming from GN-z11 must have travelled to get to us, giving them the tools to estimate its overall distance from Earth.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Right: The galaxy is a staggering 13.4 billion light years away

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C: When the Sun lights the Moon from behind

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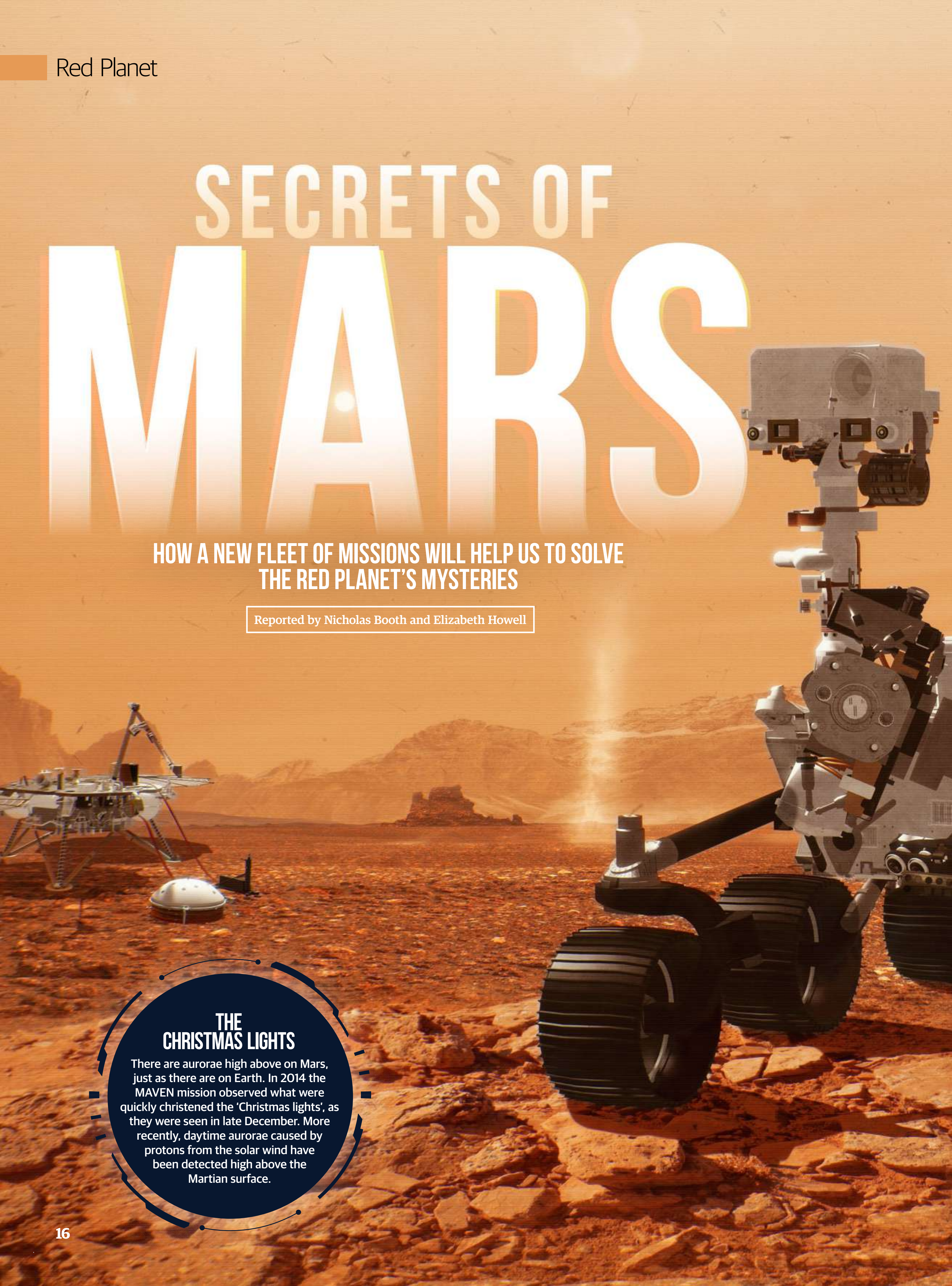
SECRETS OF MARS

HOW A NEW FLEET OF MISSIONS WILL HELP US TO SOLVE THE RED PLANET'S MYSTERIES

Reported by Nicholas Booth and Elizabeth Howell



THE CHRISTMAS LIGHTS

There are aurorae high above on Mars, just as there are on Earth. In 2014 the MAVEN mission observed what were quickly christened the 'Christmas lights', as they were seen in late December. More recently, daytime aurorae caused by protons from the solar wind have been detected high above the Martian surface.

The Red Planet keeps a tight rein on its secrets. Many enduring mysteries about Mars have taken years of research to resolve, only to be replaced by newer, ever more puzzling ones. If exploring Mars directly over the last five decades has taught us one thing, it is surely that even today – after intense scrutiny from above, on the surface and now probing directly below – the Red Planet can still spring surprises.

Mars is a freezing, desiccated desert on which a constant swirl of dust plays havoc with delicate instruments. Worse, mechanical failures and anomalies cause headaches for those who have sent robots in their stead. Even so, most researchers wouldn't have missed any of it for the world.

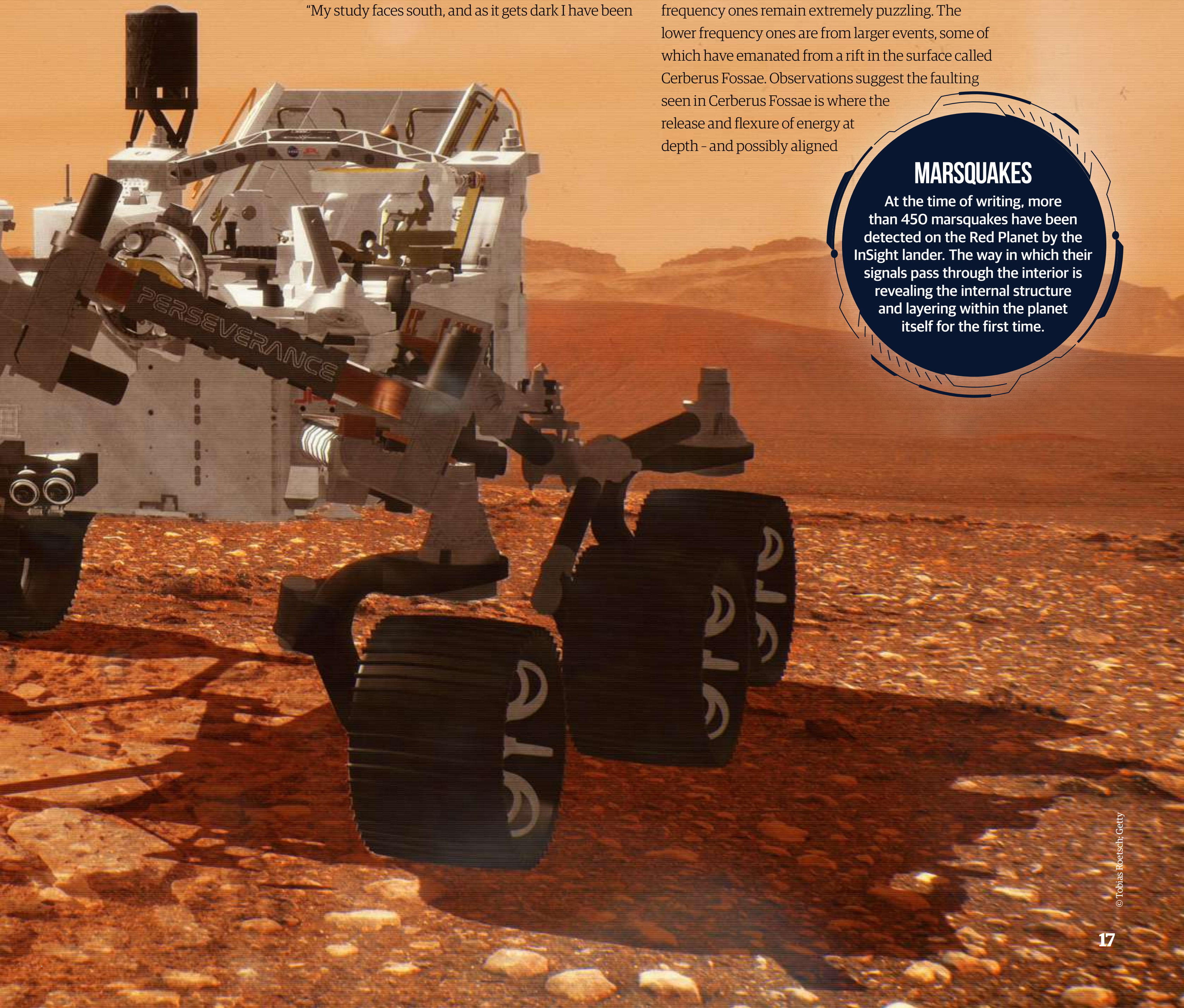
"It's been an amazing journey," says Dr Anna Horleston, a seismologist based at Bristol University. "My study faces south, and as it gets dark I have been able to see Mars rise through the window in the early evening. And then I can look down at my screen at wiggly lines, and know they have come from there."

Those lines represent one of the holy grails of Mars research, the telltale signs of seismic activity. NASA's InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) has been making detailed maps of the Martian interior for the first time. It had long been suspected that the Red Planet had a small core and was more Moon-like in terms of its activity, certainly not as seismically active as Earth. Since the InSight landing in November 2018, more than 450 marsquakes have been identified. Residual heat deep within the interior is still causing small-scale seismic waves .

"We have characterised these signals as either high or low frequency," notes Horleston. The higher frequency ones remain extremely puzzling. The lower frequency ones are from larger events, some of which have emanated from a rift in the surface called Cerberus Fossae. Observations suggest the faulting seen in Cerberus Fossae is where the release and flexure of energy at depth – and possibly aligned

MARSQUAKES

At the time of writing, more than 450 marsquakes have been detected on the Red Planet by the InSight lander. The way in which their signals pass through the interior is revealing the internal structure and layering within the planet itself for the first time.



© Tobias Roetsch; Getty

with the faults themselves – is taking place. Some of the team believe that lava as recent as 10 million years old is the cause. The question of how much heat is still radiating outwards from a core that seems to have switched off early in Martian evolution remains one of the greater secrets yet to be revealed.

METHANE

The most elusive substance in the atmosphere of Mars today is methane, present in trifling quantities. But the European Trace Gas Orbiter has yet to find any, though recently it may have shown why. A new series of hitherto unsuspected spectral lines may be ‘hiding’ the underlying signals of methane.

InSight is all about statistics: the more observations it makes, the greater the accuracy of its findings. For most of 2020, however, its landing site in Elysium Planitia has been windy, drowning out many of the highly sensitive measurements needed to identify marsquakes. Worse has been the cumulative effect of the fine dust which swirls around. “A lot of dust has accumulated on the solar panels,” says Horleston. “We knew we would lose power over the course of the mission, but we have more dust than we’d hoped.”

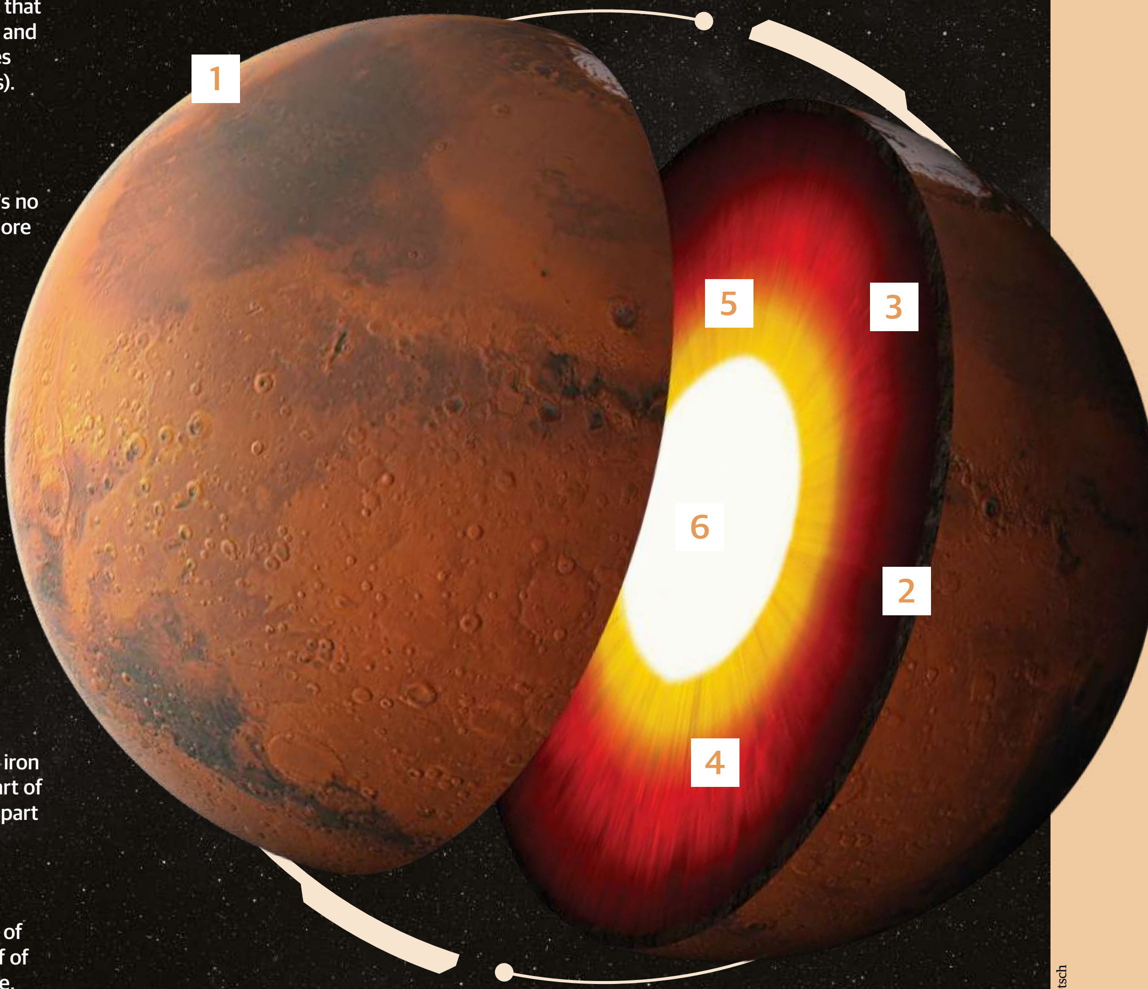
As greater amounts of dust have flowed into the local atmosphere, the amount of sunlight has been reduced. Worse, the spacecraft’s solar panels – which provide it with power – have been covered. The mission is now literally running on half the power it had just after landing. Into 2021, that means there will be a delicate balancing act for InSight’s operations team. Some instruments may have to be selectively switched off because of power limitations. The lander’s robotic arm, for example, should have been put to rest in the spring of 2019. It actually spent most of its first year on Mars being used to scoop, scrape, prod, poke and push. The InSight ‘mole’ – a heat probe designed to drill into the surface and take measurements – would just not burrow. Even now nobody is sure what the problem was.

The Red Planet often adheres to Murphy’s law. The mole would have worked everywhere else on the Red Planet where there have been landings. Now, when it has finally started to do its job, power is becoming an issue. Dust devils have also been seen at other landing sites, which whizz by and act as vacuum cleaners on solar panels. Not so with InSight. It is now essentially hibernating for the winter.

The mission will allow researchers to connect up another important part of the Martian jigsaw puzzle. The atmosphere itself is very dry, cold and tenuous, and is believed to be the remnant of a much denser atmosphere. Understanding how it degraded remains the underlying secret of the Martian climate.

INSIDE THE RED PLANET

Recent research has been unearthing some juicy secrets beneath Mars’ surface



1 A thick crust
Data from NASA’s InSight appears to indicate that Mars’ crust is between 20 and 37 kilometres (12 and 23 miles) thick on average. Earth’s crust averages between 32 and 48 kilometres (20 and 30 miles).

2 Two to three layers
The crust is divided into either two or three layers of different types of rock, although there’s no confirmation as to what they are yet. Three is more likely when analysis of Martian meteorites and geochemical models are taken into account.

3 Marking the boundary
Using seismology data from InSight taken in 2019, a study by researchers at Rice University concluded the boundary between the crust and mantle is about 35 kilometres (22 miles) below the position of InSight.

4 A cooler mantle
InSight found the mantle to be cooler than expected. Largely dormant mantle, it is thought to be richer in iron, potassium and phosphorus when compared to Earth.

5 Olivine-wadsleyite transition
The mantle also contains a zone where the mantle’s mineral structure changes: magnesium iron silicates form the mineral olivine in the upper part of the zone, and wadsleyite is formed in the lower part due to high pressures and temperature.

6 A hot core
Mars has a metallic molten-liquid core made of iron, nickel and sulphur. It makes up roughly half of the planet’s total diameter. Since it doesn’t move, Mars doesn’t have a magnetic field.

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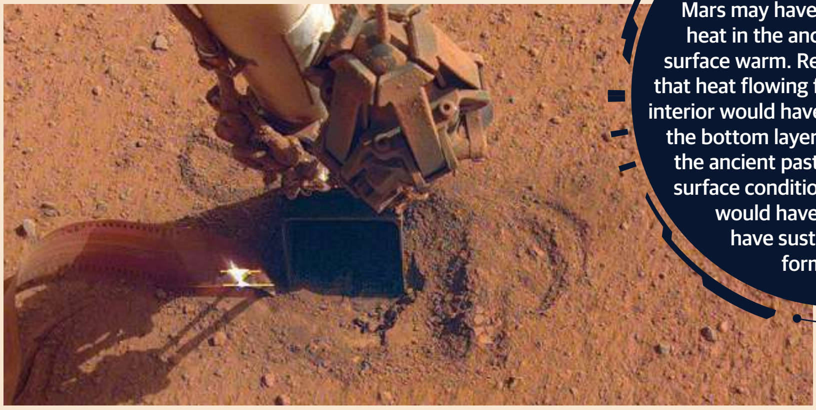

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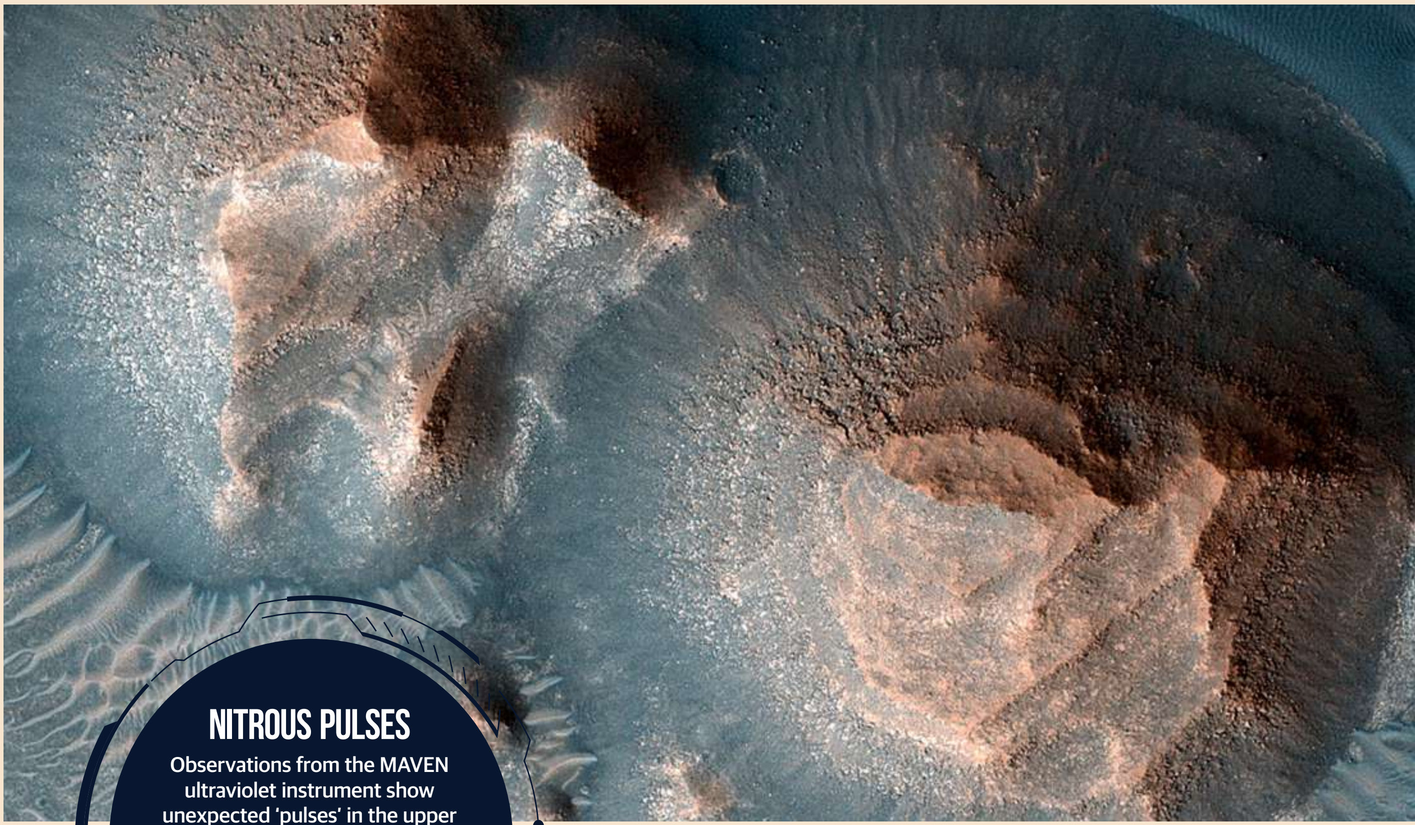
GOING UNDERGROUND

Mars may have had enough internal heat in the ancient past to keep its surface warm. Researchers determined that heat flowing from within the Martian interior would have been sufficient to melt the bottom layers of thick ice sheets in the ancient past. No matter what the surface conditions were like, the heat would have been enough to have sustained life had it formed then.



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Top (clockwise): After much effort and frustration over 2020, the InSight 'mole' - its temperature sensor - has now finally burrowed beneath the surface

The French-British seismometer package shown under its cover, now resting on the surface of Mars

Layered rock on the Martian surface is shaped by wind erosion, as can be seen in this view of Arabia Terra

NITROUS PULSES

Observations from the MAVEN ultraviolet instrument show unexpected 'pulses' in the upper atmosphere. They are caused by high-altitude winds bringing molecules down into the lower atmosphere, which then 'pulse', accelerating chemical reactions that cause nitric oxide and the ultraviolet glow observed.

The Mars Atmosphere and Volatile Evolution (MAVEN) orbiter has been looking at how the interior of the planet relates to how the solar wind interacts with the atmosphere's outmost layers.

"MAVEN was intended to look at the upper atmosphere today as a way of understanding loss to space," says its lead scientist Professor Bruce Jakosky of the University of Colorado. "The mission's overarching goal was to determine the role that loss of atmosphere to space played in the changing climate through time."

The complex cocktail of chemistry involved shows that the outer atmosphere is selectively pulled apart by the solar wind. "The bottom line is that loss to space accounted for the single largest removal of gas from the atmosphere and was a driving factor in changing the climate some 3.7 billion years ago."

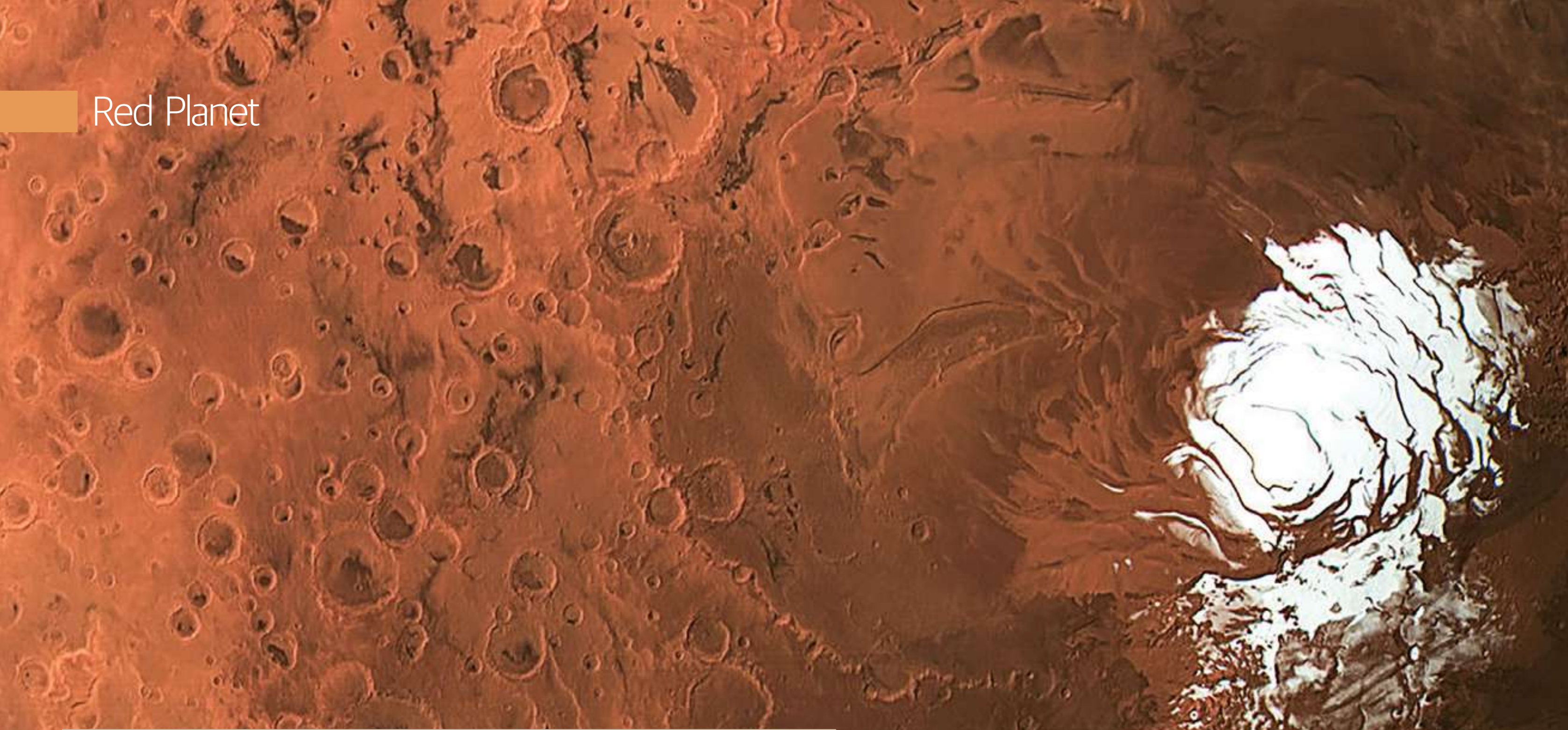
In discovering the first aurora in the upper atmosphere, MAVEN has also shown how solar storms have aided and abetted that loss to space. The enhancement implies that they may have been large enough to have been the determining factor in the overall loss rate in the ancient past. "Solar storms were larger and occurred more often early in history," says Jakosky. "They may have driven the overall loss rate."

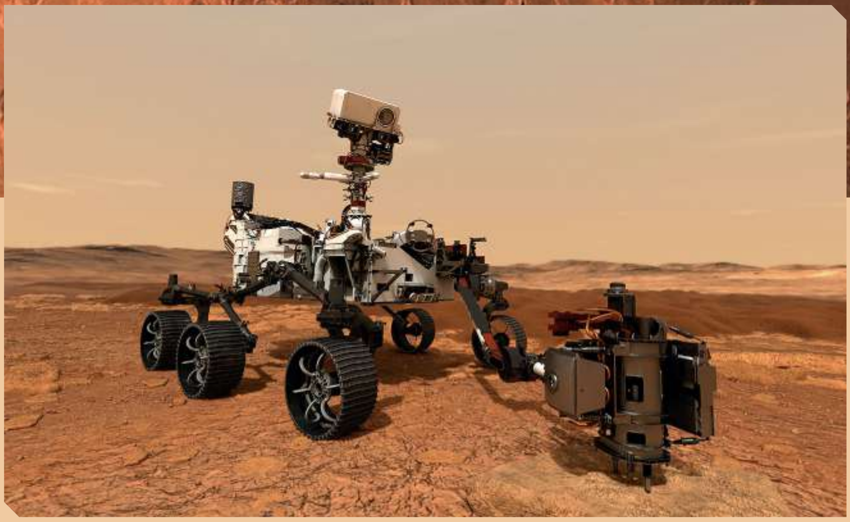
Orbital missions have also found that the upper atmosphere is a lot 'friskier' than previously thought. The next arrival, the Hope orbiter, launched in July 2020 by the United Arab Emirates (UAE), will add to that understanding. Hope's instruments will get the 'synoptic view' - a larger overview, fitting in with other missions where there are gaps in knowledge.

More recently, instruments aboard the Trace Gas Orbiter have watched how the minute amounts of water vapour on present-day Mars have reached higher altitudes in greater amounts during global dust storms. The question of how exactly local dust storms 'go global' remains another mystery.

"It may be that dust storms on Mars are basically chaotic," says Dr Claire Newman, an atmospheric specialist at Aeolis Research in California, who is working across several current missions. "A slight year-to-year difference in the availability of surface dust or local surface wind patterns might make the difference between a global storm or nothing at all."

Due to arrive at Mars on 9 February, the Hope mission will examine the coupling between the lower and upper atmosphere - the exchange of atmospheric energy and mass. "This was highlighted from MAVEN observations as being important," notes Jakosky.





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> “WE WILL CAREFULLY CHECK SUCH DATA TO LOOK FOR OTHER POSSIBLE EVIDENCE OF THE PRESENCE OF BODIES OF WATER” ELENA PETTINELLI

“Hope will, by making simultaneous observations of the lower and upper atmosphere and by using synoptic measurements of the lower atmosphere, help better understand atmospheric dynamics and the energy transfer.”

The forecast for Martian meteorologists is looking good. InSight has the most sophisticated weather-measuring instruments ever sent to Mars. To date, Murphy's law has brought bad luck in obtaining decent wind measurements on earlier missions.“Wind is crucial to so many things on Mars,” notes Newman. “That includes how the surface erodes and changes over time.” Atmospheric scientists also need wind measurements to calibrate their understanding of how localised flows feed into the overall global circulation of the planet. She adds: “Having the highest rate of pressure data” – up to 20 measurements a second on InSight – “has also opened up a whole new world on turbulent variations.” The main area of interest is just how different levels in the atmosphere connect with each other. “We've known for a while that we don't quite understand how dust, once it is lifted from the surface, ends up producing high-altitude dust layers, even during the ‘clear’ season when no major dust storms occur.”

Such measurements will also help in understanding how climate has evolved on Mars. How the Martian atmosphere has changed is inextricably linked with the question of water. The most intriguing insights in recent years have come from itinerant rocks which have been flung from the Martian surface in the ancient past. As remarkable as it sounds, an estimated half a tonne of the Red Planet arrives here on Earth every year. In particular, one remarkable meteorite landed in the Sahara Desert in 2011, and is usually known as ‘Black Beauty’ to those who have examined its various fragments.

It is hardly a Rosetta stone, rather an amalgamation of material that has been blasted and fused together on the surface of Mars. Analysis has shown it is made up of a jumble of fragments – ‘a hopeless mess’ in one assessment – which have fused together at different times throughout the planet's geological history. “The idea is that this meteorite is made up of breccia,” says Dr Jane MacArthur of Manchester University, who studied it for her PhD. “That is, it consists of lots of broken fragments in a fine-grained matrix.”

Meteorite falls have been described as the only free lunch in planetary astronomy. To carry on that analogy, researchers have no idea who the chef was, what ingredients were used or even which shift they were working on. Regarding Black Beauty, what we're

WATER IN BLACK BEAUTY

The various elements of the ‘Black Beauty’ meteorite – discovered in the Sahara Desert in 2011 – show a range of ages of material which fused together on the Martian surface. Most recently, a team in Tokyo has analysed minerals and chemistry in one part of the rock which show there was water present on or in the Martian crust 4.4 billion years ago during an impact which melted part of the crust.

© ESA

Left: Wind has shaped the visible surface of the south polar ice cap, and beneath the surface it has been suggested there may be 'lakes' of liquid water

Bottom left: Over the next decade, samples will be taken by the Perseverance rover in Jezero crater and left as caches to be picked up by a later 'fetch' rover for return to Earth

trying to do is unravel all the component parts in MacArthur's assessment.

It is unusual in that it is clearly composed of rocks which have been excavated near the surface and not from deep within the interior. As such, Black Beauty shows how the crust and the atmosphere have interacted over time. In places, its youngest material - roughly 1.5 billion years old - contains ten-times more water than other Martian meteorites. Taken at face value, this suggests much more water has flowed on the Red Planet in the recent past than was previously believed. But is there liquid water on Mars today?

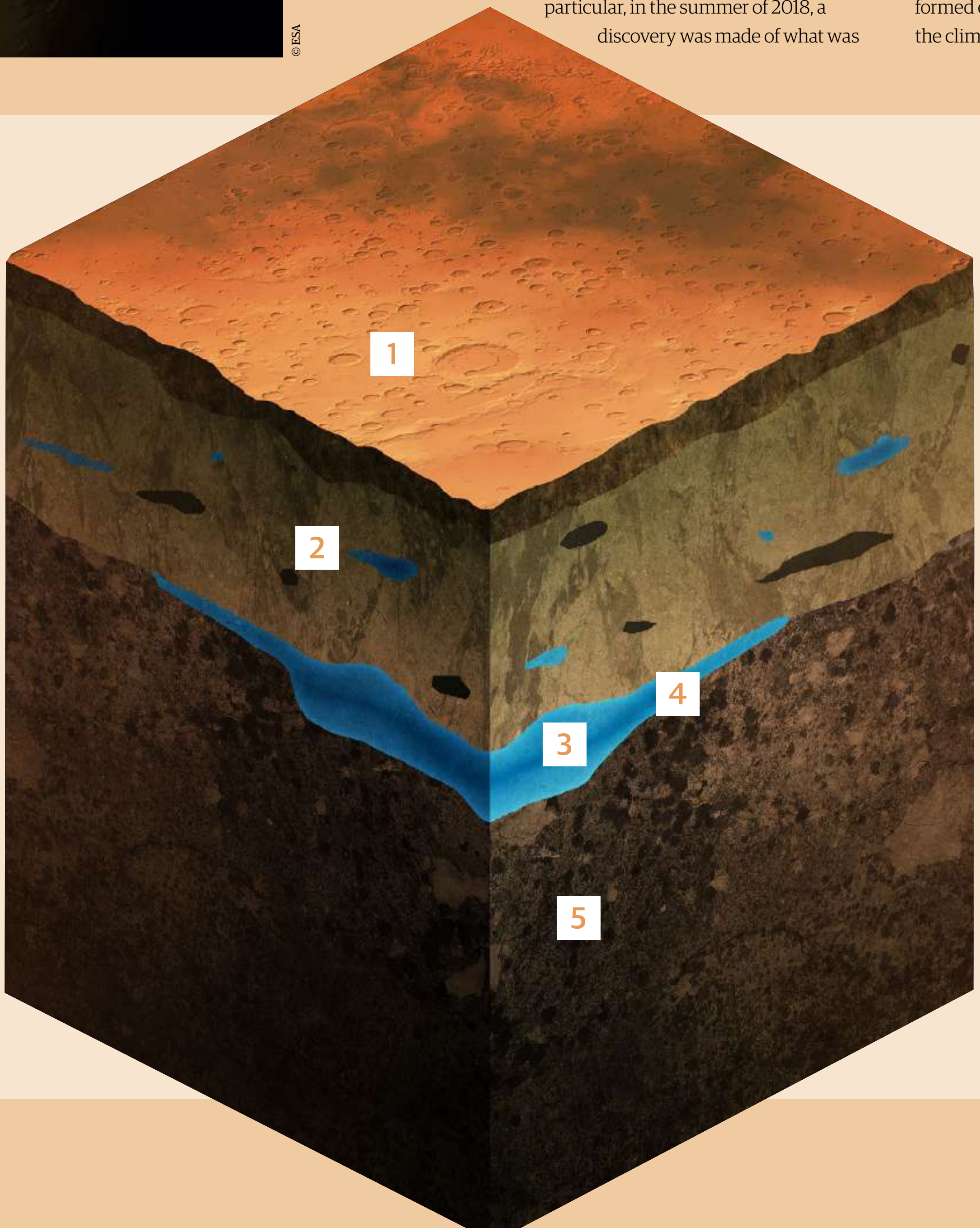
If there is, it will have long since frozen beneath the planet's surface in an extensive aquifer. So far the inference of subsurface ice has been made from radar measurements taken from orbit. Radar signals penetrate the surface, and their reflection indicates the presence of ice in several places. In particular, in the summer of 2018, a discovery was made of what was described as a large lake under the south pole. What lead scientist Dr Elena Pettinelli of Roma Tre University called "anomalously bright subsurface reflections" were observed by a radar instrument on the Mars Express orbiter.

Now, two years later, greater numbers of passes by the same instrument have refined the observations. A total of 134 'profiles', as the team calls the radar observations "are crossing each other and covering a larger area". Centred on what they interpreted as a lake, a different analytical technique has now been employed. This, the team points out, is the exact same procedure used to look for subsurface water under terrestrial ice sheets in polar regions.

"We have analysed the radar signals looking for specific features that on terrestrial radar are associated with the presence of liquid water at the base of the ice sheets," says Pettinelli. This new approach implies that subglacial meltwater was formed elsewhere on Mars in the ancient past, when the climate was more clement.

WATER AT THE POLES

Mars today is freezing, with no signs of liquid water on the surface. But repeated passes over the south pole of the planet by the Mars Express radar instrument have shown that there may be 'lakes' underneath them, increasing the likelihood of life being present.



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WATER ON MARS

1 DRY SOIL

Martian soil forms a dusty layer. It's made up of nutrients such as sodium, potassium, chloride and magnesium.

2 SIGNS OF ICE

Ice which once formed on the surface of Mars is thought to have become buried, leaving an immediate permafrost subsurface with young ice in its pores.

3 POCKETS OF WATER

Water ice is locked within cavities across the mid-latitudes of the planet. Some chunks of frozen water have been found just beneath the surface.

4 SUBSURFACE RESERVOIRS

Underground lakes are thought to exist far beneath the surface. A high level of salt or heat from Mars' interior could even result in them being liquid.

5 THE FOUNDATION

The water would lie above an impermeable bedrock, which has a high concentration of sulphur.

The findings are controversial. Some believe the observations are more to do with how the radar is modelled. Others think the water would be more sludgy and is perhaps a subsurface layer of high groundwater abundance. Water would have to be very salty and heated to stay warm.

The Italian team acknowledges there is no current explanation for any subsurface heat sources on Mars, unlike Antarctica, which hosts several subsurface lakes which are kept above freezing. Hypersaline water could also remain above freezing. "We think that perchlorate salts, that are ubiquitous on Mars, could help to keep the water liquid," Pettinelli says. "We will carefully check such data to look for other possible evidence of the presence of bodies of water."

All these questions are the curtain raiser for the next decade, when space agencies will attempt to return samples from Mars. The Red Planet is evidently a complex world – no less complex than our own, even though it doesn't have plate tectonics or an ocean. "Mars is also an excellent place to study planetary processes that tell us about habitability and the potential for life, the evolution of climate and the atmosphere and the evolution of a terrestrial planet during its first billion years," concludes Jakosky. "It's a compelling planet, with lots left to explore to find answers to major questions."

DUST STORMS

In 2018, one of the most fierce global dust storms on Mars covered the planet. Spacecraft watched how the dust fed into the atmosphere, enhancing the amount of atmospheric water vapour taken to the upper atmosphere, which is then broken down and lost to space.

Nicholas Booth
Space science writer
Nicholas worked on *Astronomy Now* and served as a science writer for national newspapers. He co-wrote *The Search for Life on Mars.*

Elizabeth Howell
Space science writer
Elizabeth holds a PhD in aerospace sciences and is a contributing writer to **Space.com**. She co-wrote *The Search for Life on Mars* with Nicholas Booth.

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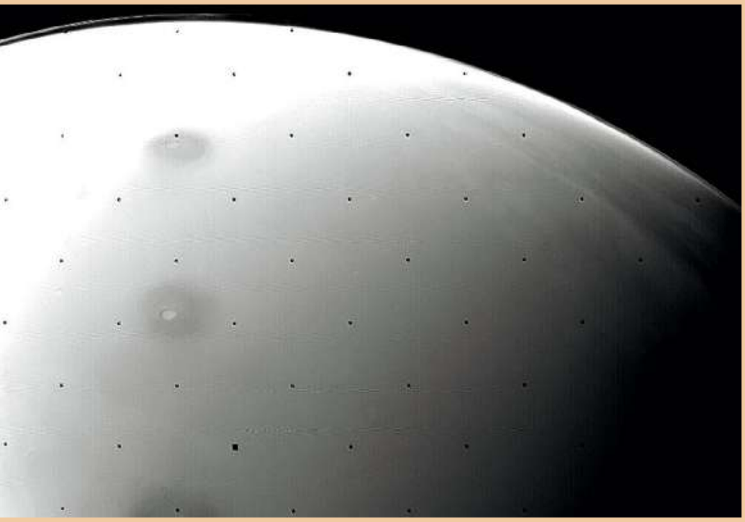
Below: Dust storms on Mars can whip up and cover the whole of the surface. This was the view in 1971 when Mariner 9 – the first successful orbiter – arrived. As the dust cleared, the giant volcanoes were seen for the first time



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2021 ONWARDS: PLANS FOR STUDYING THE RED PLANET

On 9 February 2021, the UAE's Hope mission – a small test orbiter – will arrive at the Red Planet, carrying mainly American instruments. Next the Chinese Tianwen-1 mission will enter a long, looping orbit. A few months later a lander will be dropped from the orbiter, which will see the starting gun on China's own ultimate ambitions to return samples – as it has just done from the Moon.

If all goes to plan, NASA's Perseverance will land on Mars on 18 February. Along with other scientific objectives, it will be looking for signs of past life on the Martian surface. The mission will land come what may. It will barrel straight in, aiming at a bullseye 45 kilometres (28 miles) across: Jezero crater. The good news is that NASA has done this before. The bad news is that two European landers have crashed in this same region already – Beagle 2 and Schiaparelli. There will be the sky crane that drops it down and the 'seven minutes of terror' as NASA waits for the signals to confirm a successful touchdown.

2021
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ROSALIND FRANKLIN

This European rover – built in Stevenage – will be taken down to the surface by the Russian Kazachok lander. Because of problems with its parachute systems and complications from the coronavirus pandemic, its launch has been pushed back to the autumn of 2022. Both lander and rover will land in Oxia Planum in the spring of 2023.

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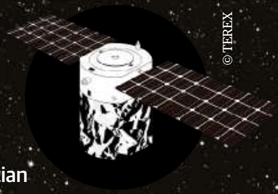
TERA-HERTZ EXPLORER (TEREX)

The Mars Terahertz Microsatellite is a Japanese mission designed to take both an orbiter and lander to Mars. The latter will measure oxygen isotope ratios in the atmosphere to better understand the chemical reactions that replenish the Martian atmosphere with carbon dioxide.



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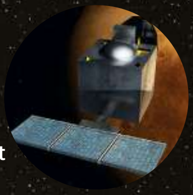
MANGALYAAN-2 (MARS ORBITER MISSION 2)

India's follow-up mission to its first orbiter may carry a lander and rover as possible additions. While there is no official announcement of when it will be launched, it will likely be in 2024 at the earliest.



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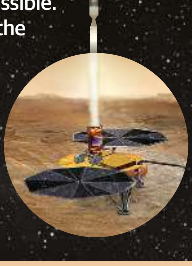
MARTIAN MOONS EXPLORATION (MMX)

Japan plans to send a probe to Mars' largest moon Phobos in 2024. It will drop a small lander on Phobos, collect samples and return them back to Earth. The samples are expected to arrive in July 2029.

© NASA

MARS SAMPLE RETURN

After launch in July 2026, a lander will carry its own Mars ascent rocket for the return journey, as well as a 'fetch' rover. This will land in Jezero crater in August 2028, as close to Perseverance as possible. The rover is a 'minicab' designed to retrieve the samples and take them to the ascent rocket, which will fire into low-Mars orbit with the sample-return canister in spring 2029. A European-built orbiter will 'catch' the canister with the samples inside it and then transfer them to a return mission, which will land back on Earth some time in 2031.



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ULTIMATELY LARGE TELESCOPE ON THE MOON

With a big enough telescope, we could look back to the first stars – and from another world

As we look up into the night sky, one of the most counterintuitive aspects for the general observer is that they are looking back in time. As Douglas Adams said: "Space is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts compared to space." With the speed of light in a vacuum fixed at 300,000 kilometres (186,411 miles) per second, it governs how long it takes for the light we see to travel from celestial objects. A second from the Moon, eight minutes from the Sun, 4.3 years from the nearest star and so on, meaning the stars we see in the sky are as they were years ago.

This almost time travel-like effect means that as we build larger telescopes we can see further away, and therefore further back in time. Light from a given source gets rapidly spread out as it expands in all directions as a sphere. In principle, if we have a sufficiently large telescope with a large enough light-gathering capacity, we could see far enough to see back to the first stars. Hubble, over its tremendous 30-year career, has enabled us to push towards this. Its successor, the much delayed James Webb Space Telescope, has a mirror that can collect six times more light and should let us image the very first galaxies. But a team of astronomers at the University of Texas at Austin, led by NASA Hubble Fellow Dr Anna Schauer, have proposed that an old NASA concept for a large lunar-based telescope would be large enough to see the first stars, which formed before galaxies.

Ground-based observatories can produce tremendous results, but will always be peering through the atmosphere – thus the move towards orbiting telescopes – but being in free orbit brings its own challenges, especially as the size of structures grows. So the team are looking to combine the best aspects of both, and build a telescope on the Moon. If built, the Ultimately Large Telescope would be based in a crater in the lunar polar regions, and could be as much as 100 metres (328 feet) across, over 1,700 times the collecting area of Hubble. While not being steerable, it would stare deeply into one region of space, collecting huge quantities of light and data. However, producing and transporting such a large astronomical reflecting surface to the Moon presents significant challenges. The study group has proposed an interesting way around this: a liquid mirror.

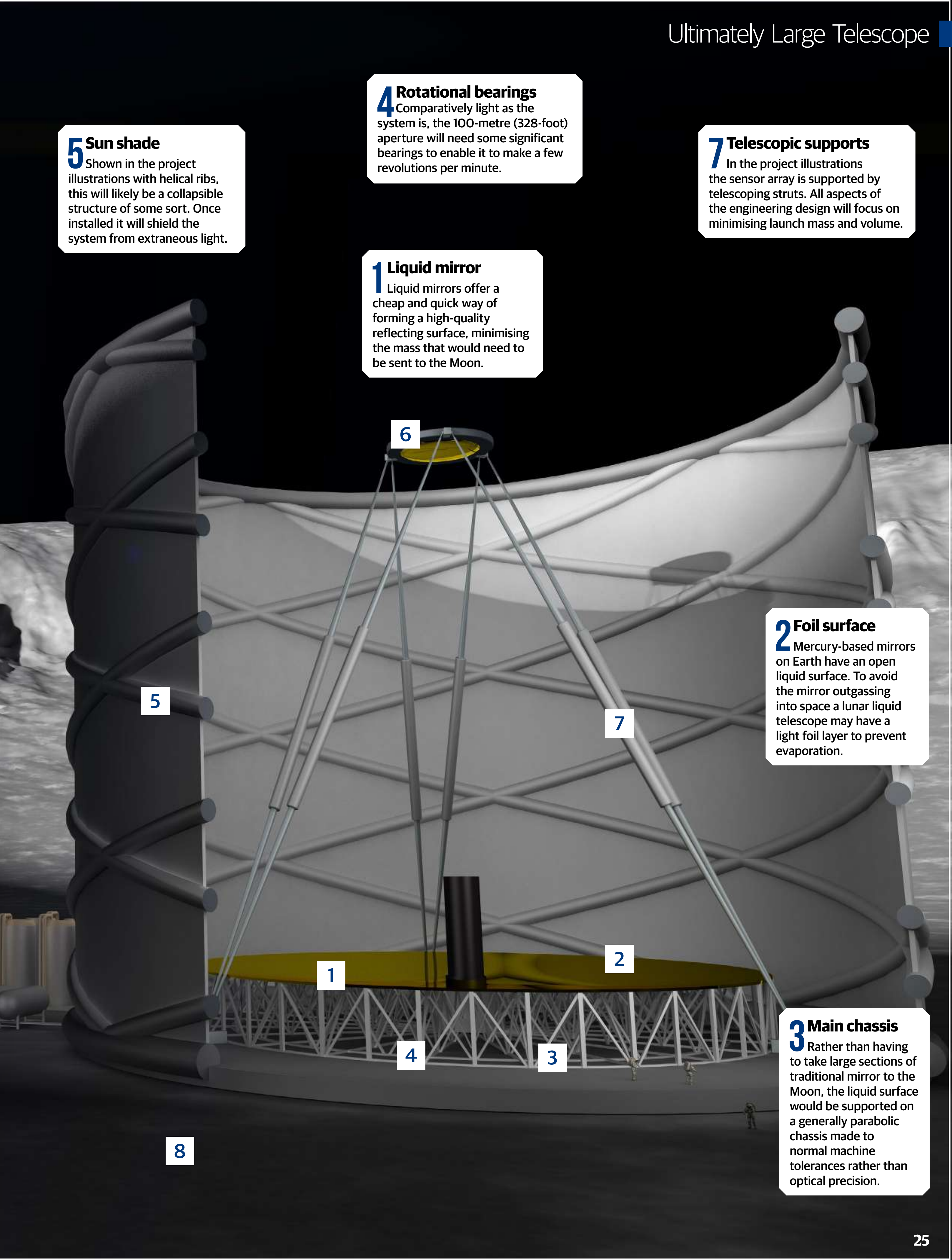
If a circular tray of liquid is spun, the liquid is partly flung out towards the edge, dipping down in the middle, and the surface forms a parabolic dish. The big advantage of liquid mirrors is cost saving in manufacturing. The largest yet built was the six-metre (20-foot) Large Zenith Telescope (LZT) operated by the University of British Columbia, the mirror of which was calculated to be one per cent the cost of a glass mirror the same size.

> "AS WE BUILD LARGER TELESCOPES WE CAN SEE FURTHER AWAY"

The LZT used a thin layer of mercury on a generally parabolic carrier. A prospective Moon-based telescope couldn't use liquids in the vacuum of space, so may feature a thin foil layer that is supported and shaped by the liquid underneath. While it may be some time before we see such a facility constructed, the project has been nicknamed the Ultimately Large Telescope. If it comes to fruition, the lunar observatory may be able to show us the very first light of the universe.

6 Sensor array
Rather than bouncing the light out to an eyepiece, the sensor array can be mounted directly in place of the secondary mirror.

8 Lunar poles
Liquid telescopes can only look up. At the equator they will scan the sky. Placed at the poles the ULT will be able to stare deeply into one region, reaching out for the first stars.



1 Liquid mirror

Liquid mirrors offer a cheap and quick way of forming a high-quality reflecting surface, minimising the mass that would need to be sent to the Moon.

2 Foil surface

Mercury-based mirrors on Earth have an open liquid surface. To avoid the mirror outgassing into space a lunar liquid telescope may have a light foil layer to prevent evaporation.

3 Main chassis

Rather than having to take large sections of traditional mirror to the Moon, the liquid surface would be supported on a generally parabolic chassis made to normal machine tolerances rather than optical precision.

4 Rotational bearings

Comparatively light as the system is, the 100-metre (328-foot) aperture will need some significant bearings to enable it to make a few revolutions per minute.

5 Sun shade

Shown in the project illustrations with helical ribs, this will likely be a collapsible structure of some sort. Once installed it will shield the system from extraneous light.

7 Telescopic supports

In the project illustrations the sensor array is supported by telescoping struts. All aspects of the engineering design will focus on minimising launch mass and volume.

© Adrian Mann

INTERVIEW

BIO

Dr Becky Smethurst

Smethurst is an astrophysicist at the University of Oxford and star of astronomy-themed YouTube channel 'Dr. Becky', where each week she explains either an unsolved mystery, a weird object found in space or general space news with an unnatural level of enthusiasm. Her channel has over 100,000 subscribers.

DR BECKY SMETHURST

"THERE'S NOTHING MUTUALLY EXCLUSIVE ABOUT BEING A SCIENTIST"

All About Space talks to the astrophysicist and YouTube sensation about life, the universe and everything

Interviewed by Connor Hansford

How would you describe your research to somebody outside your field?
The job of a researcher is to answer the questions that no one knows the answers to. To do that you obviously have to think of the question first. My specific research is all to do with the connection between galaxies and the supermassive black holes that we find at the centre of every single one. Something that massive we think has a big effect on everything around it, and my job is to work out whether feeding this black hole has a negative impact on the galaxy.

I notice you use data to infer quenching histories. Can anything be done to improve these inferences in the future?
What you're trying to do is model how many stars a galaxy is forming based on how much light I'm getting from that galaxy, so that's the inference bit. You observe one thing, but you want to know another thing. We can use different data to improve this inference. Instead of just looking at how much light there is, we look for what's called emission-specific wavelengths due to elements that are there.

Hydrogen is fuel for star formation, so if there's lots of it you know you're forming lots of stars. We can use those kinds of fingerprints that are much more precise to improve our inference, but it also comes with improving computational models and statistical methods. Research that's going on right now in computer science and maths will eventually improve that kind of inference as well.

'Understanding the physical processes that have shaped our universe is the fundamental goal of astrophysics' - so begins your PhD thesis. How close are we to achieving this goal?
I think that there is so much more that we don't know than we do know, and I think it would be arrogant of us to assume that we're even close to figuring out the properties of the entire universe. We are so small, and the universe is so big. It's fantastic what we've done so far. The fact that we can measure black hole masses and figure out how massive galaxies are and how they've evolved is incredible, but I don't think we're anywhere near to being done. And I don't think any astrophysicist would ever want to be - we'd be out of a job, and knowing everything is boring.

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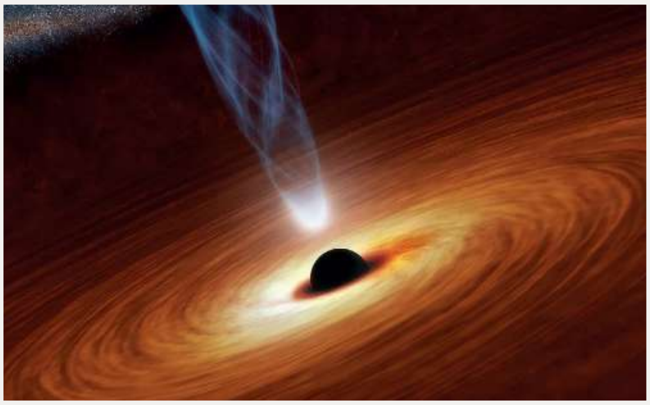
Left: Competition for the European Southern Observatory's VLT is fierce - not everyone is successful

Below: All galaxies have a supermassive black hole at their centre



© NASA

And you're always disagreeing...

But the disagreeing is part of the process, right? Eventually the evidence piles up in favour of one interpretation, and that's why in current science it can seem we don't know what we're talking about. I am blown away that they've managed to come up with a vaccine [for COVID-19] in nine months.

And your university is at the forefront of it!

It is, yeah! The physics department has been involved in some of the diagnostics, using machine learning techniques that have been developed for a physics application for diagnostic tests instead.

You recently applied to use the Multi Unit Spectroscopic Explorer (MUSE) on the Very Large Telescope (VLT) to study bulgeless galaxies. What do you hope to discover, and was your application successful?

One of the questions distracting me was how black holes grow in galaxies that have not merged with other galaxies. When galaxies merge they grow in mass, and you tend to ruin these nice spiral shapes and just end up with a big blob. What about galaxies that haven't had a merger, but still have a supermassive black hole? Are they piddly black holes, or have they managed to grow at the same rate but in a different way?

What I wanted to do was see if galaxies without bulges were somehow feeding their black holes by themselves, perhaps by funnelling gas down their spiral arms. Unfortunately it wasn't successful, but I will try again in the next round!

> “IT'S ARROGANT OF US TO ASSUME THAT WE'RE CLOSE TO FIGURING OUT THE PROPERTIES OF THE ENTIRE UNIVERSE”

What would you say is your biggest frustration within astrophysics?

Two things. The first is how long a project takes. From start to finish it can be over a year, and it's very difficult to stay focused in that time, especially for someone like me who really enjoys the gratification of scratching things off a to-do list. The second thing is more about the culture of astrophysics and academia as a whole. I am a junior research fellow, so I'm sort of halfway between being a PhD student and a permanent member of staff at a university. That's great because you have the freedom to get jobs around the world, but in nine months you're going to be applying for new jobs because of the way the academic job cycle works. You lose yourself in the science and then realise, 'oh my gosh, someone could take this away from me.' That's what's scary about it.

Right: Scientists use light and other factors to find areas of star formation

As a consumer of science media, what is your biggest frustration with the way your field is communicated?

The assumption that we are all geniuses. You have to work at it. Not everyone is a musical prodigy, and it's the same thing with physics. If someone is massively interested in space and astronomy but they're not good at maths, practise and you will get better at it. It's also frustrating that everyone looks like Einstein. There is a huge, diverse range of people that do astrophysics. If you're interested in it, don't let anyone tell you it's too hard, because only you can make that decision. One assumption I want people to get away from is that you can't like science and maths because you have to stop liking something else. There's nothing mutually exclusive about being a scientist.

How can science communication build bridges between the public and the research you're involved with?

A lot of science communication is done by fantastic people, but they're often removed from what we call the frontline of research. By having more academics on YouTube who are in that field and staying up to date, it's possible to relay that information back to the public without middle people. Middle people do fantastic work, but I think there's something to be gained by getting it straight from the people who are fully immersed in it. One way that can really help kids learn science is teaching them the history of how we figured stuff out. If more scientists taught like that, I think it would resonate more.

How has your research impacted your outlook on the world?

That's a difficult one. It's changed my perspective on the change that someone can bring about. When you're doing research like that and you're asking such specific questions, it makes you realise how important it is to step back and see the bigger picture. You're more aware of how something small can affect things in a big way. A lot of people say when they look at the night sky they get freaked out by the scale of it. By doing the research, you realise something that seems small can have a big impact. I don't feel weird when I look at the night sky. The scale of it actually makes me very hopeful, which is nice!

You recently uploaded a video of you watching *Star Trek: The Next Generation* for the first time. Is it realistic for young people growing up now to want to be a starship captain one day?

It's realistic for kids growing up now to want to be an astronaut! The space industry is growing so those opportunities are becoming more common, but starship captain I think is still a long way off. Our nearest star system is four light years away. Voyager 1, which is the furthest spacecraft from us at the minute, would still take around 70,000 years to get there. And I don't think any form of warp drive is coming any time soon.

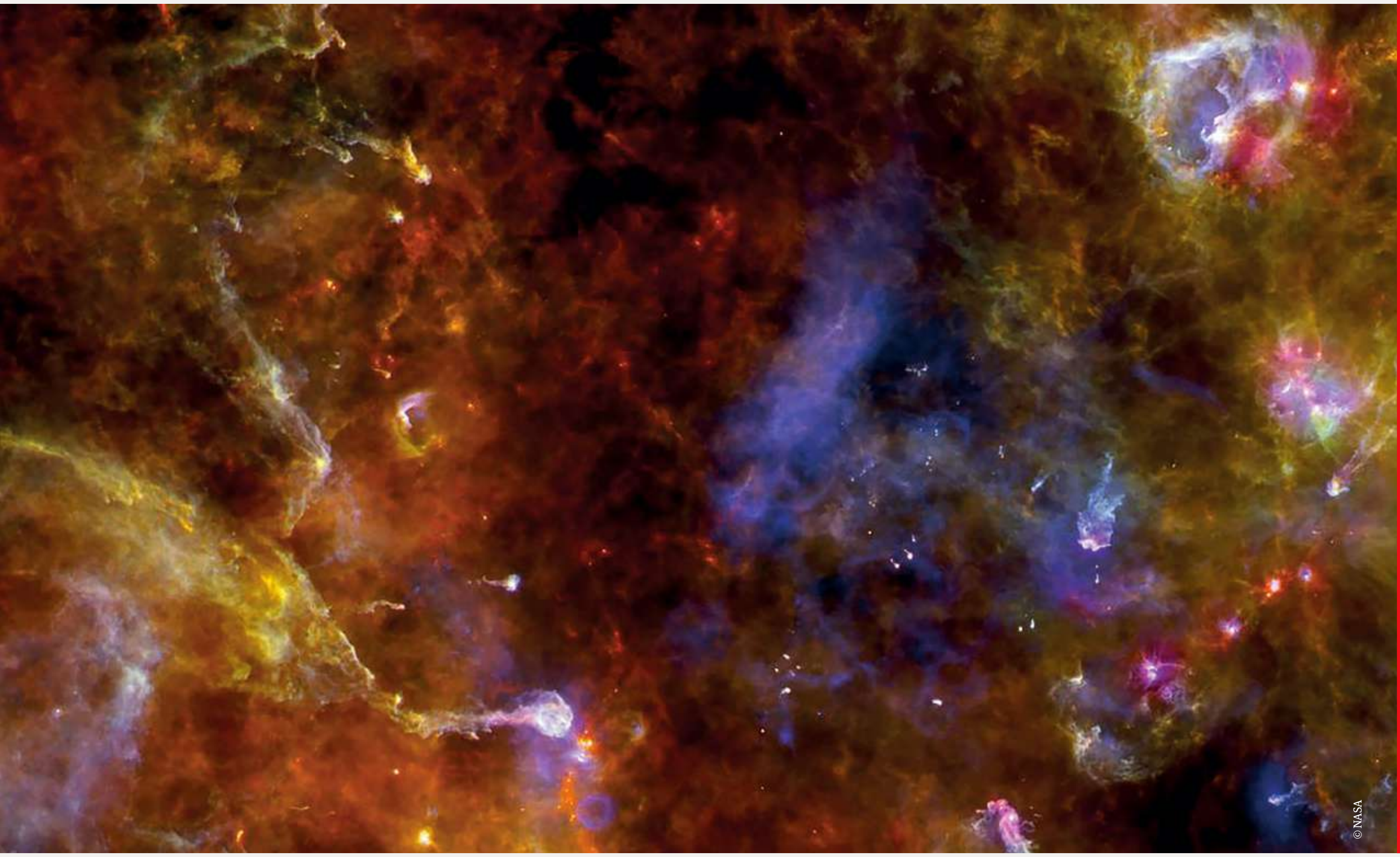
Can you do *Doctor Who* next?

I really want to do *Doctor Who*!

Space: 10 Things You Should Know

Smethurst is the author of *Space: 10 Things You Should Know*, which is available now from all good bookshops and online retailers.

Space
10 Things You Should Know
Dr Becky Smethurst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RISE OF THE EXOPLANET HUNTER

The next generation of alien-world-seeking spacecraft will revolutionise our understanding of distant planets

Reported by Baljeet Panesar

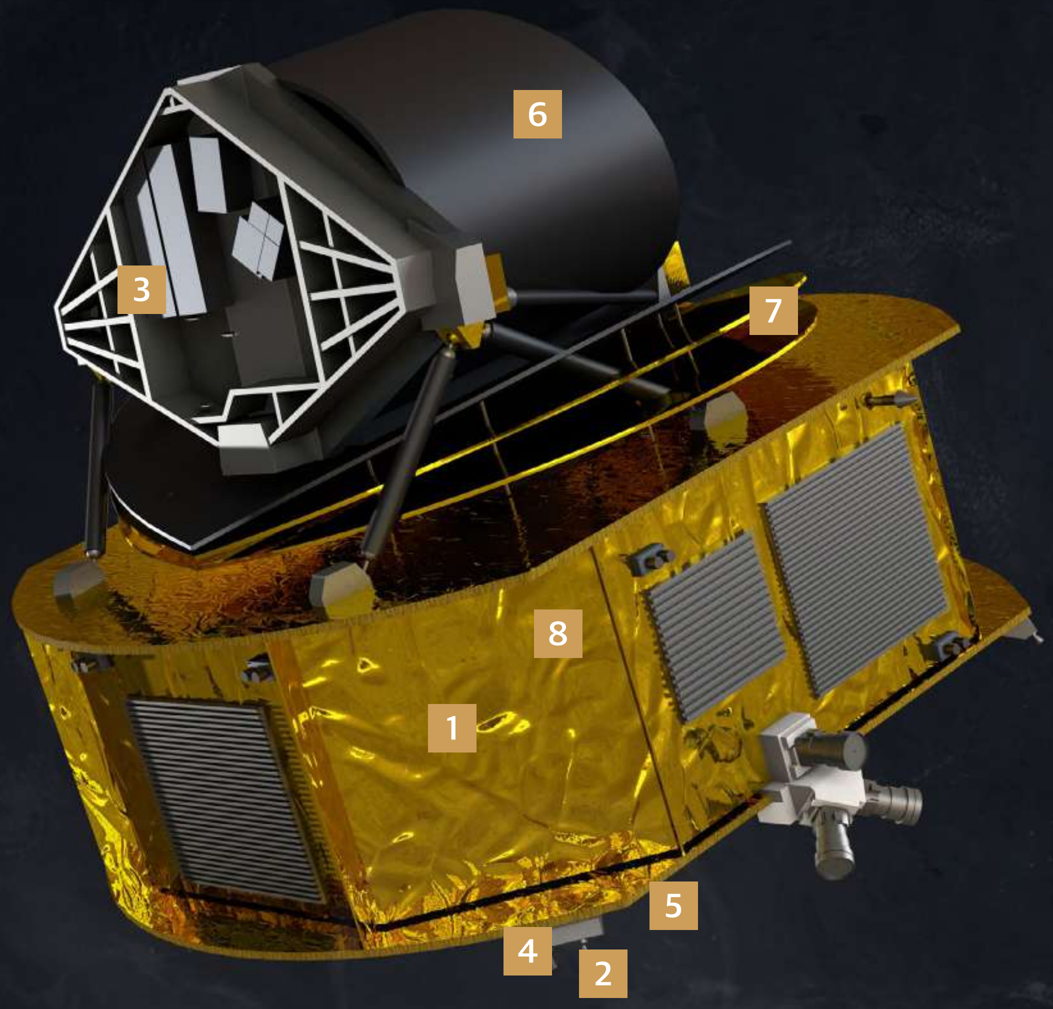
Almost 30 years ago, two astronomers changed the way we viewed our place within the universe. They had discovered the first extrasolar planets, or exoplanets - planets that orbit stars other than our Sun. Since then we have discovered over 4,300 new and fascinating worlds - planets that orbit two stars, a planet that is so close to its host star that it's being ripped apart and a planet that's covered in hot lava. Some even orbit stars like our Sun in the habitable zone where liquid water could exist - and there are hundreds of billions of intriguing new worlds in the Milky Way alone that are yet to be discovered and explored.

To explore these unknown worlds, the Atmospheric Remote-sensing Infrared Exoplanet Large-survey, or Ariel, is set to launch at the end of the decade. The mission was selected by the European Space Agency (ESA) as its third dedicated exoplanet hunter to launch within ten years, and the fourth 'medium-class' project in the Cosmic Vision program, back in 2018 after beating a mission to study energetic particles around the Earth and an X-ray telescope. For the past five years, scientists have been working on Ariel's science goals and instruments, which has involved collaboration between more than 50 institutes in 17 countries. NASA will also contribute an instrument to the mission.

Ariel will address one of the key themes of the ESA's Cosmic Vision program: what are the conditions for planet formation and the emergence of life? "Ariel will study what exoplanets are made of, how they formed and how they evolve by surveying a diverse sample of about 1,000 extrasolar planets in visible and infrared wavelengths simultaneously. It is the first mission dedicated to measuring the chemical composition and thermal structures of hundreds of transiting exoplanets, enabling planetary science far beyond the boundaries of the Solar System," says Professor Günther Hasinger, the ESA's director of science.

In recent years we have made great progress in the study of exoplanets. However, Ariel is different to the other exoplanet missions that have been launched in the past. "Previous space observatories like Kepler, CoRoT [Convention, Rotation and planetary Transits] and TESS [the Transiting Exoplanet Survey Satellite] focused on discovering new exoplanets" says Dr Subhajit Sarkar, a research associate at Cardiff University in the UK, who works on the Ariel mission. "Unlike previous missions, Ariel does not aim to discover new planets, but instead will characterise the atmospheres of known exoplanets," continues Sarkar.

> "ARIEL WILL STUDY WHAT EXOPLANETS ARE MADE OF, HOW THEY FORMED AND HOW THEY EVOLVE" GÜNTHER HASINGER



THE ARIEL MISSION

Inside the planet explorer that could transform exoplanet science

1 FINE GUIDANCE SYSTEM

The onboard guidance system will allow Ariel to guide and focus itself on target exoplanets with high precision and stability.

2 HIGH-GAIN ANTENNA

Using the X-band frequency range, this is the main method of communication to and from Ariel.

3 THE ARIEL INFRARED SPECTROMETER

Ariel's main scientific instrument will detect molecules that are present in planets' atmospheres to work out their structure and composition.

4 THRUSTERS

Ariel will use a hydrazine monopropulsion system to perform one manoeuvre each month so that it can maintain its orbit.

5 SOLAR CELLS

Located on the bottom of the spacecraft's main body, the solar cells generate about one kilowatt of power to provide Ariel with all of its power needs.

6 TELESCOPE

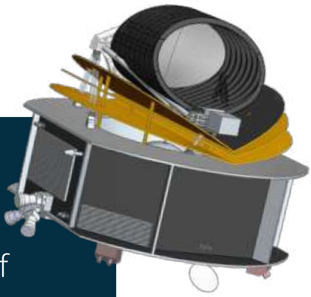
Ariel's 1.1 by 0.7 metre (3.6 by 2.3 foot) telescope will be made entirely from aluminium, and its primary mirror will be coated in silver.

7 PAYLOAD MODULE

Ariel's telescope, instruments and guidance system are cooled to -328 degrees Celsius (-559 degrees Fahrenheit).

8 SERVICE MODULE

This contains everything that Ariel needs to operate at a temperature between -20 and 50 degrees Celsius (-4 and 122 degrees Fahrenheit).



ARIEL'S OBJECTIVES

The main aims of the ESA's new exoplanet explorer

1 TO DISCOVER WHAT EXOPLANETS ARE MADE OF

Ariel is the first mission dedicated to measuring the elemental composition and thermal properties of known exoplanets.

2 TO DETERMINE HOW PLANETS AND PLANETARY SYSTEMS FORM

Observing hot worlds will give us insights into the early stages of planet formation and their first few million years.

3 TO WORK OUT HOW PLANETS AND THEIR ATMOSPHERES EVOLVE OVER TIME

Ariel will observe the 'chemical fingerprint', or spectra, of a planet's atmosphere. From this data the composition, temperature and physical processes can be determined.

The Ariel mission will focus on surveying hot and warm giants similar in size to Jupiter and Neptune to super-Earths that orbit close to their host stars, analysing a range of spectral types from hotter Sun-like, white-yellow dwarf stars to red dwarfs. Hot exoplanets, some which reach over 2,000 degrees Celsius (3,632 degrees Fahrenheit), are ideal for studying the chemistry and formation history of the planet because gases continuously circulate throughout the atmosphere, preventing the formation of layers of clouds via condensation.

Exoplanet missions are extremely important and can help us to understand our own origins and the origins of the universe. "Exoplanet studies are one of the most important and appealing fields of contemporary astrophysics," says Hasinger.

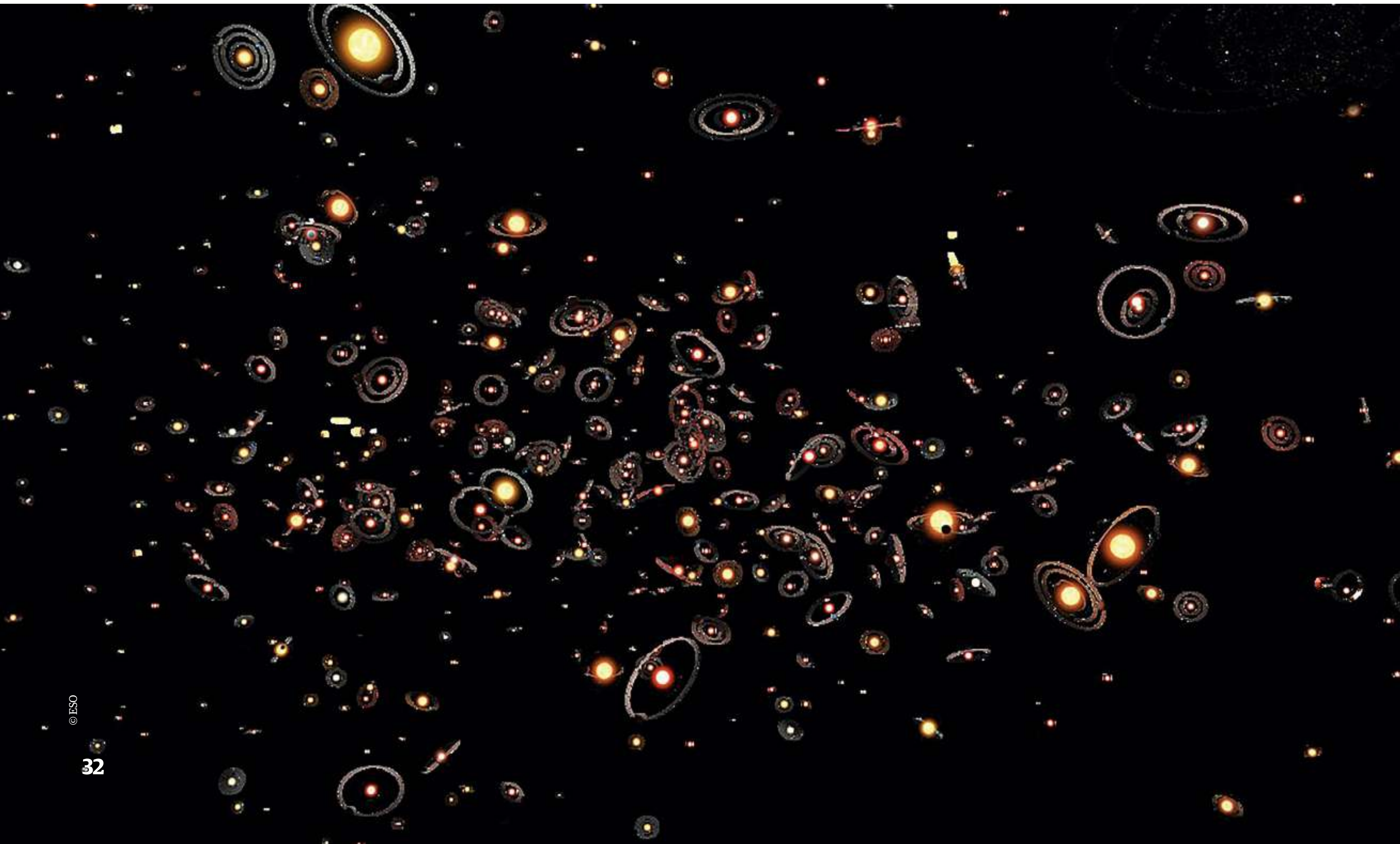
"We study exoplanets for several reasons," says Sarkar. "Firstly, to understand our own origins. Where did we come from? How did the Solar System form? What led to the formation of the Earth and the origins of life on Earth? Exoplanets allow us to test the theories of planet formation through multiple natural experiments instead of using the example of one we had before".

Although so far we have found no evidence to suggest that there is life beyond planet Earth, Ariel will rise to the challenge. "Exoplanets are part of the search for life in the universe and the age-old question of 'are we alone?' We may be able to detect biosignatures in the spectra of these worlds that reveal the presence of life. Rocky planets that orbit in the 'habitable zone' of their star – where liquid water could possibly form on the surface of the planet – are a focus for such a search. This would be one of the greatest discoveries in science, and again place our own origins in context. It may be possible one day to find out how common life is in the universe," continues Sarkar. Understanding exoplanets can also help us "better understand the processes affecting the Earth" and "may have great relevance for understanding the future evolution of our own planet," he explains.

The space observatory is currently scheduled to start its search for life in 2029, launching with Comet Interceptor from the ESA's spaceport in Kourou, French Guiana on the new Ariane 6 rocket, which is currently scheduled to make its maiden launch in 2022. The craft will take roughly six months to reach its orbit and undergo commissioning and science demonstration phases before it can start its primary mission. The space observatory will make its way to Lagrange point 2 (L2), an orbital parking spot roughly 1.5 million kilometres (930,000 miles) from Earth. The initial science mission will last for 3.5 years, with the possibility of a two-year extension.

Once Ariel is in position, the observatory will use its 0.9-metre (three-foot) diameter primary mirror to collect light from faraway stars in the visible and infrared wavelengths. Other instruments,

Below: It is estimated that every star in our galaxy has at least one planet in orbit



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including an infrared spectrometer and photometer, will perform spectroscopic analyses on the target exoplanets. A spectrum will be obtained for each target exoplanet, and like its predecessors, Ariel will make use of the transit method to study exoplanets, where the dip in starlight is measured as a planet travels in front of its host star. Sarkar explains: "Each observation will involve measuring the light from the host star for a period of time, during which the planet will transit, producing a 'light curve'. The spectrometers allow the light to be split into different wavelengths so that multiple light curves can be obtained as a function of wavelength. The 'dip' in the starlight is proportional to the planet-star area ratio and returns a planet radius with wavelength.

"While the bulk of the radius value is due to the planet body and fixed, a small amount of extra absorption occurs due to molecules in the atmosphere of the planet. These molecules absorb differently at different wavelengths, each with its own characteristic spectral 'fingerprint'. By tracing out the apparent radius variation with wavelength we obtain a 'transmission spectrum' of the atmosphere. By analysing this we can find the molecules making up the atmosphere and other properties such as temperature and the presence of clouds and hazes." Results from Ariel will be made available to the science community and the general public almost immediately. It is hoped that this approach will ensure that the Ariel mission will outperform its mission goals.

In recent years our understanding and knowledge of exoplanets has grown exponentially, and Ariel will surely further our understanding even more, perhaps more than we could ever hope or imagine, and might also help to explain our weird Solar System. "We know that planets are common around all types of stars. However, this planet population is very diverse, covering different sizes, masses, temperatures and orbital parameters. The architectures of most of these planetary systems also do not match that of our Solar System, and there are planet types, such as super-Earths and mini-Neptunes that do not occur in our own Solar System. Therefore the theories that were developed to explain the Solar System planets do not completely explain these new exoplanetary systems. We would like to understand how this complex pattern arises," explains Sarkar.

The most famous - and arguably the most successful - use of the transit method was by NASA's Kepler space telescope, which was launched in 2009. In just under ten years the number of known exoplanets rapidly grew from a few dozen to a few thousand. Over the course of its lifetime Kepler observed over 530,000 stars, looking for

HOW TO CHARACTERISE AN EXOPLANET

Ariel uses a well-established and effective method to study exoplanets

EYES ON THE SKY

Ariel's primary mirror will collect visible and infrared light from distant star systems and focus it onto the spectrometers.

ARIEL'S SPECTROMETERS

These will separate light into a rainbow to create a chemical fingerprint of a planet, detecting well-known and more exotic elements in the atmosphere.

SEARCHING FOR A DIP

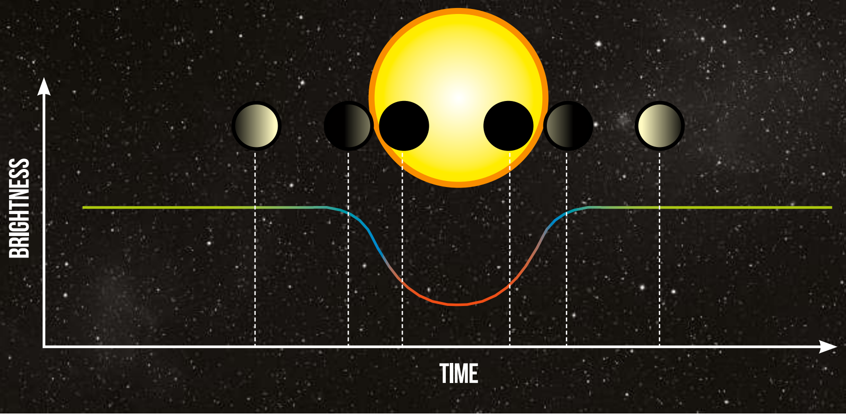
Ariel finds planets by using the transit method. When a planet passes in front of its star, it blocks some of the star's light, producing a dip in the light curve.

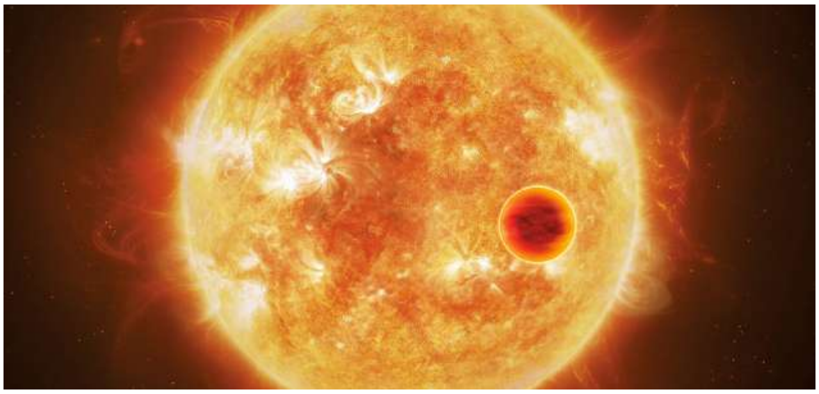
ESTIMATING PLANET PROPERTIES

Astronomers can estimate the orbit and mass of the exoplanet by measuring the frequency and amount of dimming.

EXOPLANET CENSUS

After studying the stars and planets of other distant planetary systems, Ariel will help us to better understand our cosmic neighbourhood.

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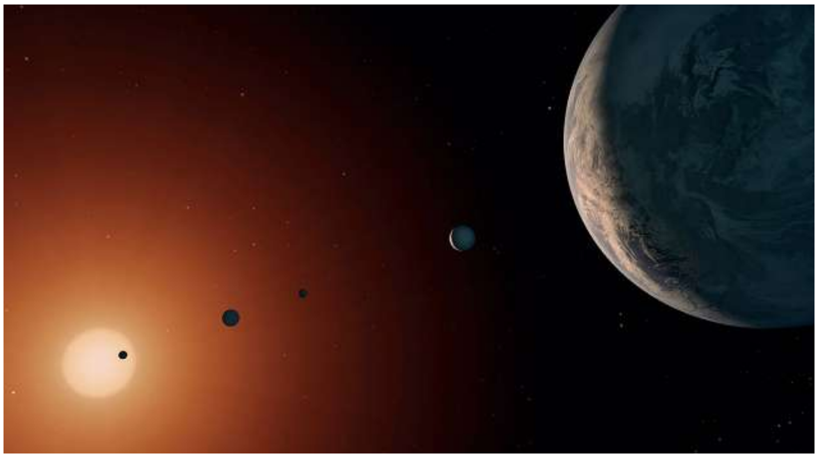
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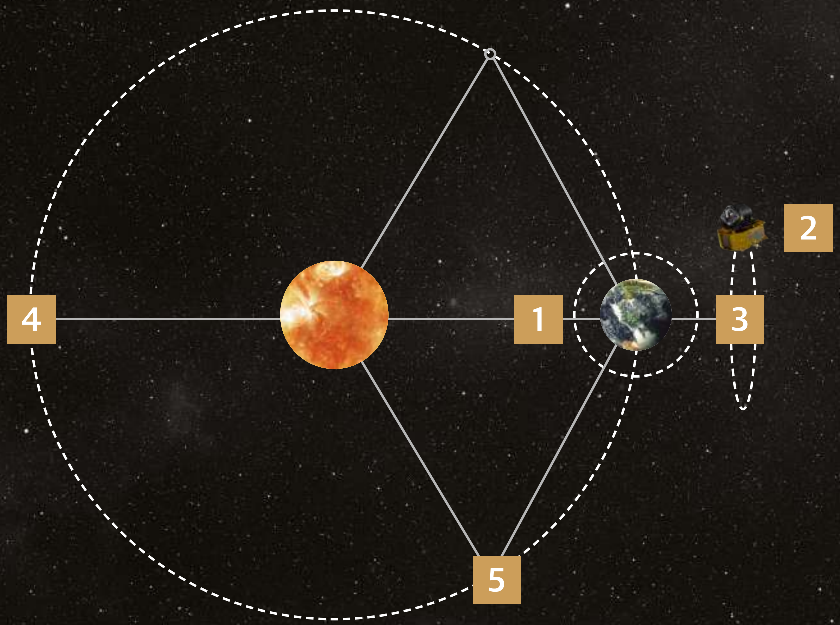
Top: Ariel will be the first space telescope to probe the atmospheres of strange worlds, focusing on hotter planets

Left: An artist's impression of what the TRAPPIST-1 system looks like from TRAPPIST-1f

ARIEL'S OBSERVING SPOT

The space observatory's home is perfectly positioned for searching for alien worlds



1 OBSERVING THE SUN

Partway between the Sun and Earth is Lagrange point 1, where the Sun can be observed without interruptions.

2 ARIEL'S ORBIT

The Ariel spacecraft will be placed in an orbit that is 1.5 million kilometres (930,000 miles) from Earth for at least four years.

3 A GRAVITATIONAL BALANCING ACT

Sitting at Lagrange point 2, Ariel is shielded from the light of the Sun and has a clear view of the entire sky for exoplanet observations.

4 THE SUN'S FAR SIDE

Hidden behind the Sun on the opposite side of Earth, this point hasn't yet been used by space observatories.

5 THE LAGRANGIAN TROJANS

Stable points that lie 60 degrees ahead (L4) and behind (L5) Earth. Dust and asteroids accumulate in this region.

the characteristic dips in starlight. Analysis of data from Kepler suggests rocky, Earth-like planets are common, that planets and solar systems are very diverse and that planets can develop around stars that are very different to our Sun.

Kepler's successor, NASA's Transiting Exoplanet Survey Satellite, or TESS, was specifically designed to search for Earth-sized planets that orbit stars that are less than 300 light years from Earth. After monitoring more than 200,000 stars and covering an area of sky 400-times larger than Kepler, TESS has so far discovered over 95 new worlds. Hundreds – if not thousands – more will continue to be discovered over TESS' extended mission. Most of these new worlds are larger than the Earth but smaller than Neptune.

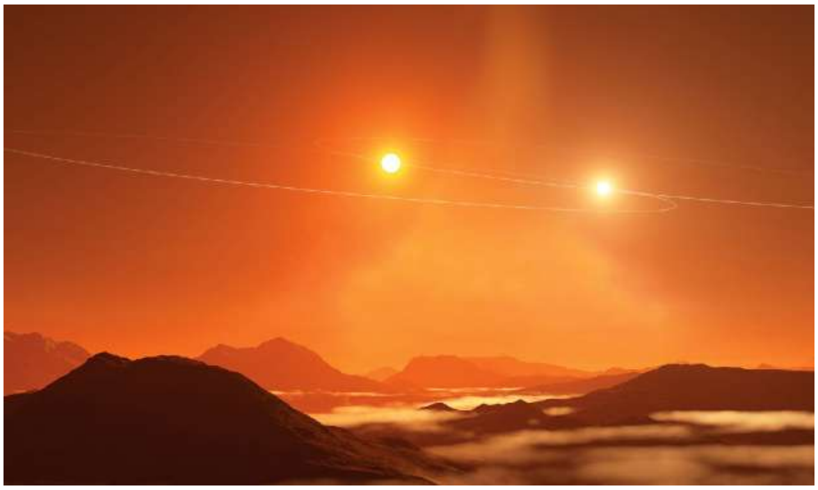
Ariel will revolutionise what we understand about exoplanet atmospheres, and scientists are already excited. "Just like Kepler transformed our understanding of exoplanet demographics, I believe Ariel will be transformative for the field of exoplanet science. No other mission will produce the number of spectra that Ariel will, which will allow us to answer population-based questions about formation and evolution, as well as unprecedented insight into the physics and chemistry of exoplanet atmospheres," says Sarkar.

"Ariel is the first large spectroscopic survey of exoplanets, and as a result we are pioneering methods and statistical techniques that will be applicable to future exoplanet surveys, including those that may focus on habitable worlds and the search for life. I am excited about the possibilities of using the data to constrain the various theories we have for planet formation and evolution, leading to a 'theory of everything for planets'. However, perhaps even more exciting will be discovering the things we didn't think about or never knew could occur," Sarkar continues.

For thousands of years, humans have looked up at the sky in awe of the stars. In our quest to satisfy our curiosity we have built rockets, spacecraft and telescopes to explore the farthest reaches of the cosmos. In just 30 years we have learned so much about exoplanets, but this decade promises to reveal even more about these alien worlds. We may be getting closer than ever before to finally finding the answer to the ultimate question: are we alone in the universe?

Baljeet Panesar
Research Editor
Baljeet holds a degree in chemistry and serves as the Research Editor on **All About Space** and its sister title **How It Works**.

Right: Double sunsets like that on the *Star Wars* world of Tatooine may be just as common as those on single-Sun worlds



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MEET THE EXOPLANET HUNTERS

The current and future spacecraft that will search for and characterise strange worlds in this decade and beyond

TESS

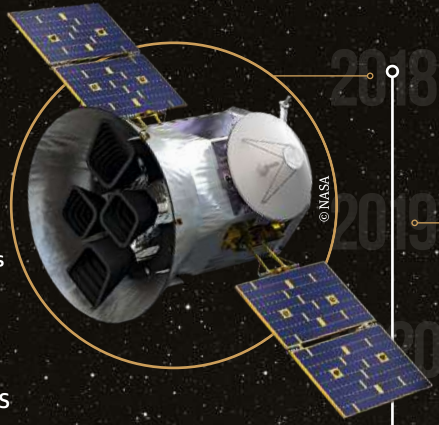
Date launched: 18 April 2018

Mission ended: Primary mission ended on 4 July 2020; its extended mission ends in 2022

Main objective: To search for planets around nearby bright stars

Most notable achievement: Identifying an Earth-like planet, called TOI 700 d, within the habitable zone

Over the course of two years, TESS imaged about 75 per cent of the sky. Using four cameras, it imaged each 'sector' of the sky for about a month, spending the first year imaging the southern sky and its second imaging the northern sky.



JWST

Date launching: 31 October 2021

Mission ended: N/A

Main objective: The JWST will characterise the atmospheres of known exoplanets

Most notable achievement: N/A

The James Webb Space Telescope will probe the atmospheres around rocky exoplanets using transits and direct imaging. This new pair of eyes will scan the sky in infrared – wavelengths that exoplanets haven't previously been seen in – to reveal more about their nature.

© Adrian Mann

PLATO

Date launching: 2026

Mission ended: N/A

Main objective: To search for and characterise Earth-like exoplanets that sit in the habitable zone of Sun-like stars.

Most notable achievement: N/A

The PLAnetary Transits and Oscillations of stars craft will watch hundreds of thousands of stars in this four-year mission. PLATO will provide information, such as an exoplanet's radius, density and stellar irradiation, to determine whether it could be habitable.

© OHB System AG

CHEOPS

Date launched: 18 December 2019

Mission ended: Primary mission ended after 3.5 years

Main objective: To characterise the size of known exoplanets that orbit nearby bright stars

Most notable achievement: Discovering one of the hottest and most extreme planets to date – WASP-189b

The CHaracterising ExOPlanets Satellite is the first-ever mission dedicated to studying nearby stars that are known to host exoplanets. It will focus on about 500 Earth to Neptune-sized planets.

© Nicholas Forder

NANCY GRACE ROMAN SPACE TELESCOPE

Date launching: 2025

Mission ended: N/A

Main objective: To search for rocky exoplanets in and beyond the habitable zone

Most notable achievement: N/A

Roman will use a microlensing technique to survey 100 million stars. This technique will allow it to scour for 2,500 planets that orbit their star closer than Venus and farther than Pluto and are smaller in size than Mars.

ARIEL

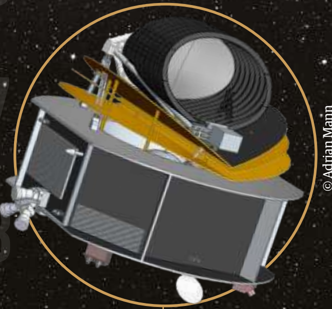
Date launching: 2029

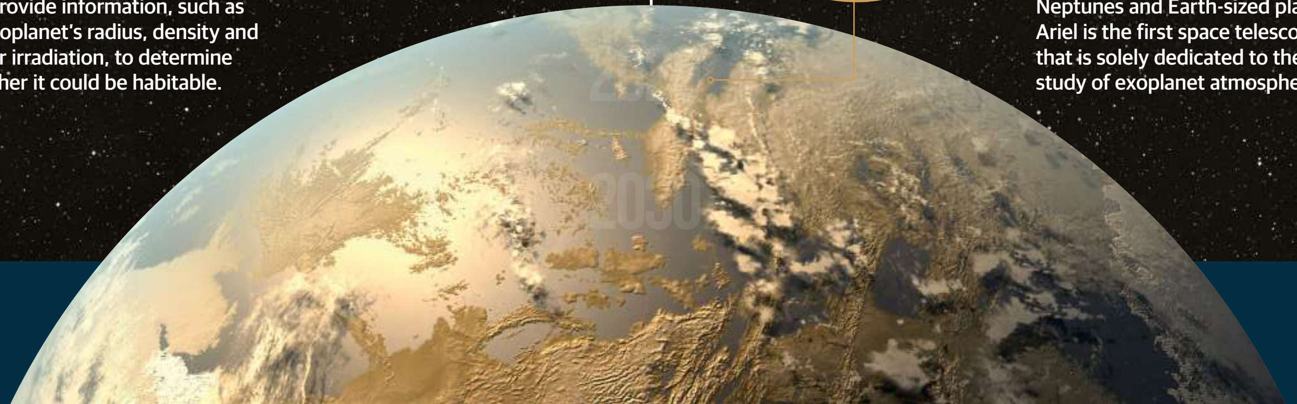
Mission ended: N/A

Main objective: Perform a large-scale survey of a wide range of exoplanets and analyse their compositions and atmospheres

Most notable achievement: N/A

This four-year mission will target roughly 1,000 exoplanets, focusing on hot and warm gas giants, super-Earths, mini-Neptunes and Earth-sized planets. Ariel is the first space telescope that is solely dedicated to the study of exoplanet atmospheres.





STAR PROFILE

Sirius

The 'Dog Star' hasn't been around very long in cosmic terms

The brightest star in our night sky, it's very hard to miss Sirius' bright blue-white glow with its high magnitude of -1.46. Although the star's official designation is Alpha Canis Majoris after the constellation that hosts it, the star has been referred to by many different names by various cultures since ancient times. The name Sirius comes from the Greek word for 'glowing' or 'scorching', fitting for a star so intense.

Sirius isn't actually that bright in comparison to giant stars like Rigel in Orion, however. It appears so vivid to us because it is one of our closest stellar neighbours. Lying only 8.58 light years from us, it is the 5th-closest stellar system to home. Sirius is actually getting closer to us at a rate of 7.6 kilometres (4.7 miles) per second, meaning it will gradually glow even brighter in the sky in the future.

In 1844, German astronomer Friedrich Wilhelm Bessel observed that Sirius behaved strangely, following a wobbly course through the sky. He suggested that there might be a hidden mass orbiting a common centre of gravity with Sirius, with an orbital period of around 50 years. Because the mass of the object would have to equal about that of the Sun to cause the disruption in Sirius' motion, Bessel's idea was met with some scepticism.

18 years later, however, these assumptions were proven correct when American astronomer Alvan Clark spotted a new small star near Sirius. Astronomers didn't know it at the time – and wouldn't for about five decades – but they had just observed the first white dwarf star, a small but massive stellar remnant. This companion, dubbed Sirius B, would have once been a main sequence star like Sirius A, both born at the same time from the collapse of a cloud of interstellar gas and dust.

Sirius B is estimated to have weighed about five solar masses before it began to exhaust its fuel and swelled into a red giant. By comparison, Sirius A is just over two solar masses. As heavier stars burn out faster and brighter, this explains why the larger star entered this stage much earlier in life. About 124 million years ago the bloated red giant began to shrink, turning into the white dwarf we see today. It will continue to fade as it exhausts all its fuel, burning out in approximately 2 billion years and ending life as a hypothetical black dwarf. If Sirius B was still a bright star like its companion today, the light from the pair would be able to cast shadows on Earth.

Because the system is only around 250 million years old, most scientists doubt that the stars host any planets. Even if there was a planet discovered, too little time has passed since the formation of the stars to allow for life to evolve. The expansion of Sirius B would have also plagued any planets in the vicinity with massive amounts of radiation. Sirius has about 600 million years left before it too swells into a red giant and dies, joining its companion.

Source:Wikipedia Commons © IMellostorm

Left: Sirius has a smaller white dwarf companion

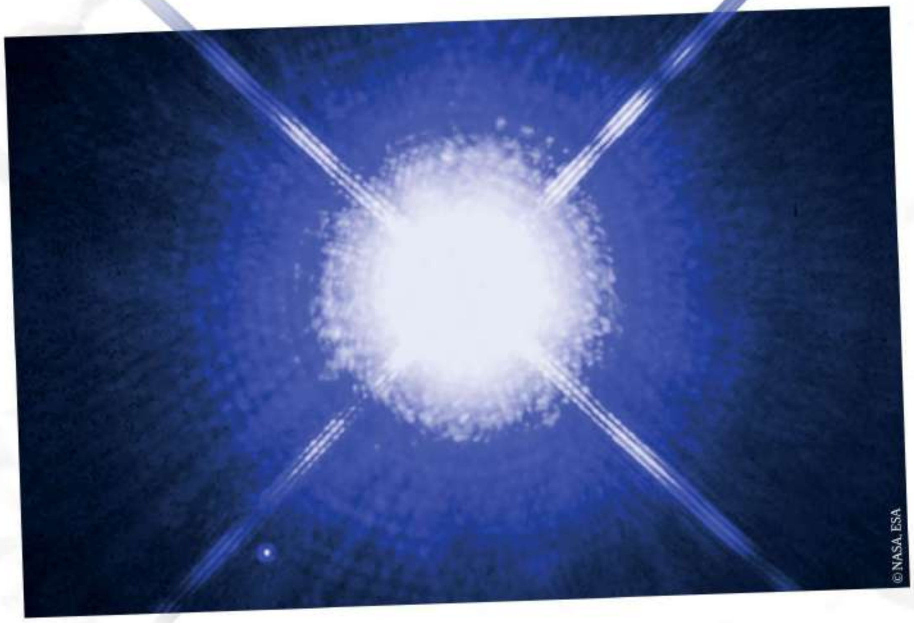
“SIRIUS COMES FROM THE GREEK WORD FOR ‘GLOWING’ OR ‘SCORCHING’”

© NASA, ESA

NEWS FROM SIRIUS

Hubble snaps Sirius B

Despite the overwhelming brightness of Sirius A making observation of Sirius B difficult, it's important that we study white dwarfs as much as possible, as we know one day our Sun will follow the same path. In October 2003, scientists used the Hubble Space Telescope to snap this image of the star system before overexposing it to highlight the small white dwarf. Using this image as a guide, Hubble's Space Telescope Imaging Spectrograph (STIS) was able to isolate light from Sirius B for study. Using this data, it was determined that Sirius B has a mass 98 per cent that of our Sun's, while analysis of its spectrum revealed the star's surface temperature to be a burning 25,200 Kelvin – around 24,930 degrees Celsius (44,900 degrees Fahrenheit). Though this remnant was once the bigger star in the binary system, at only 12,000 kilometres (7,450 miles) in diameter in comparison to its companion's 2.4 million kilometres (1.5 million miles), not only is the white dwarf now a lot smaller, Sirius B has been found to be about 10,000-times fainter than its type-A twin.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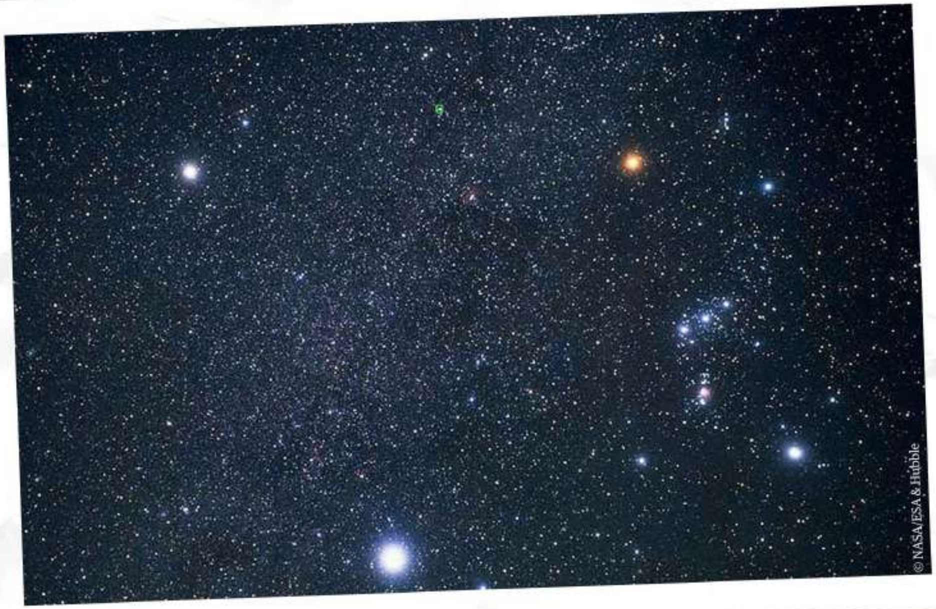
Hiding a cluster

In 2017 an open star cluster was discovered in the vicinity of Sirius using data collected by the European Space Agency's (ESA) Gaia spacecraft. Gaia was launched in 2013 with the aim of measuring the position, motion and distance of stars in our Milky Way galaxy, in the process creating a precise 3D catalogue of the objects it collects data on. The star cluster sits around ten arcminutes west of Sirius. Dubbed Gaia 1, it was an unexpected discovery by researchers counting stars in Gaia data. Although it is a high-mass cluster containing around 1,200 member stars, its close proximity to Sirius meant that glare from the star had masked the cluster, allowing it to remain unseen in ordinary telescopes. Further study has found that the open cluster weighs about 22,000 solar masses and lies around 15,000 light years away from us – far further than Sirius and its binary companion, despite their closeness in the sky. The cluster is also far older than Sirius, with its age being estimated to be around 6.3 billion years.

Finding Sirius

Sirius is hard to miss when it's shining in the sky, and can even be observed in the day under the right conditions. Part of the constellation of Canis Major (the Greater Dog), Sirius is often referred to as the 'Dog Star'. It is best seen in the Northern Hemisphere in the winter months, and in the Southern Hemisphere in the summer. Sirius is bordered by the constellations Puppis (the Poop Deck), Lepus (the Hare) and Orion (the Hunter), with Orion's belt pointing the way to the bright star. It's remarked that the Dog chases the Hare through the sky as the constellations move across it. Binoculars or even a small telescope will give a better view of the bright star, but larger and more advanced instruments will be needed if you're trying to observe Sirius A and B together – if you fancy an observing challenge, it might be worth seeking out this small stellar remnant, which has a much less impressive magnitude of +8.4. The bright stars Sirius, Betelgeuse and Procyon form an asterism known as the Winter Triangle.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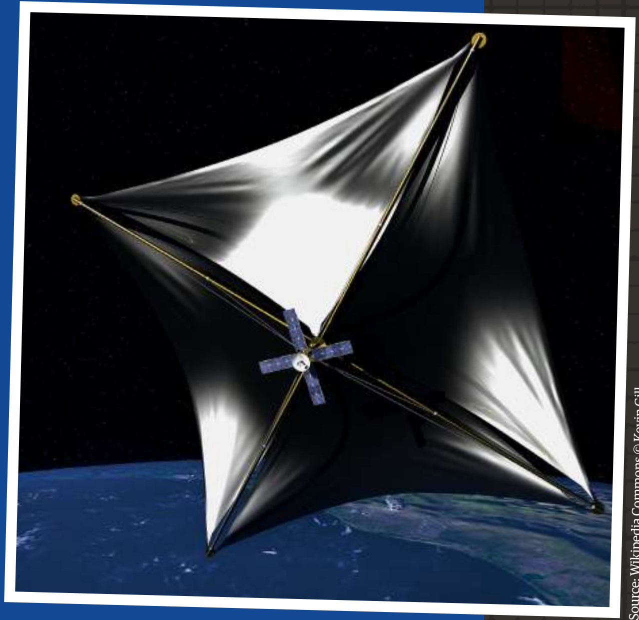
FUTURE EXPLORATION OF SIRIUS

If we're ever able to achieve anything close to light speed, Sirius would be well within reach, being only 8.58 light years away. However, though technology is advancing with time and new propulsion methods are being theorised and tested, we're still a long way off achieving these kinds of speeds. One promising piece of technology that could help with our exploration of the cosmos beyond our Solar System is known as a light sail. Light sails use lightweight mirrored sheets as sails to capture light particles, or photons. Photons don't have any mass, but they do have momentum, which the sails can capture and utilise as a method of propulsion. As the photons bounce off the reflective sail, the craft is accelerated. Photons are also an unlimited energy source, unlike rocket propellant.

Breakthrough Starshot is one initiative wanting to use light sail technology to explore other stellar systems, though the current target is the Alpha Centauri system 4.37 light years away, in part due to the detection of an exoplanet around one of its stars. The minds behind Starshot estimate that a craft could reach Alpha Centauri in 20 years if it were to perform a flyby, but decelerating and entering orbit for a longer study would make the journey 101 to 148 years.

However, a similar mission to Sirius is estimated to take less time, around 69 years. Because Sirius is twice as far away as Alpha Centauri, you'd expect the journey there to take longer. However, because Sirius is 16 times as bright, its light would allow the spacecraft to utilise more photon power to speed along its journey and then decelerate as it approached. Scientists found that the time it takes to travel to a system can be worked out from its distance divided by the square root of the luminosity, so travelling to Sirius would actually take less time.

Below: Spacecraft could utilise light sail technology to propel themselves, using stars as power stations



Source: Wikipedia Commons © Kevin Gill

SIRIUS BY NUMBERS

9,940 KELVIN
Sirius' surface is hotter than the Sun's by over 4,000 Kelvin

7
Seven British Royal Navy ships have been dubbed HMS Sirius since 1788

71%
Sirius' radius of 1.2 million kilometres (740,000 miles) is 71 per cent larger than the Sun's

-1.46
Sirius is almost twice as bright as magnitude -0.74 Canopus, the next brightest star

1868
Sirius was the first star to have its velocity measured

25X
Sirius is 25-times more luminous than our Sun

25,200 KELVIN
Sirius B currently burns much hotter than its companion

THE EVOLUTION OF SIRIUS

Date: 300 to 200 million years ago
Activity: Sirius A and B both form at the same time, though Sirius B is the larger of the binary pair. They have an orbital period of about 9.1 years.

Date: 124 million years ago
Activity: The B-type star Sirius B begins to swell into a red giant. It may have made Sirius A's metallicity higher in the process.

Date: 120 million years ago
Activity: After swelling to become a red giant, Sirius B loses energy and begins to fade into a white dwarf of about 98 per cent the Sun's mass.

Date: 1,871 years ago
Activity: Ptolemy lists Sirius in his book of star positions, titled *Almagest*, though he describes it as having a reddish colour.

Date: 159 years ago
Activity: Sirius B, a white dwarf companion star to the much brighter Sirius, is observed for the first time.

Date: Present day
Activity: Sirius A is an A-type star in the main sequence. Sirius B is separated by about 20 AU – about the distance to Uranus from the Sun – and they orbit every 50.1 years.

Date: 600 million years
Activity: After a much longer life than its companion, Sirius A will also eventually swell into a red giant as it runs out of power.

Date: 2 billion years
Activity: White dwarf Sirius B will exhaust all of its fuel and cool into a dead remnant called a black dwarf – though these haven't been proven yet.

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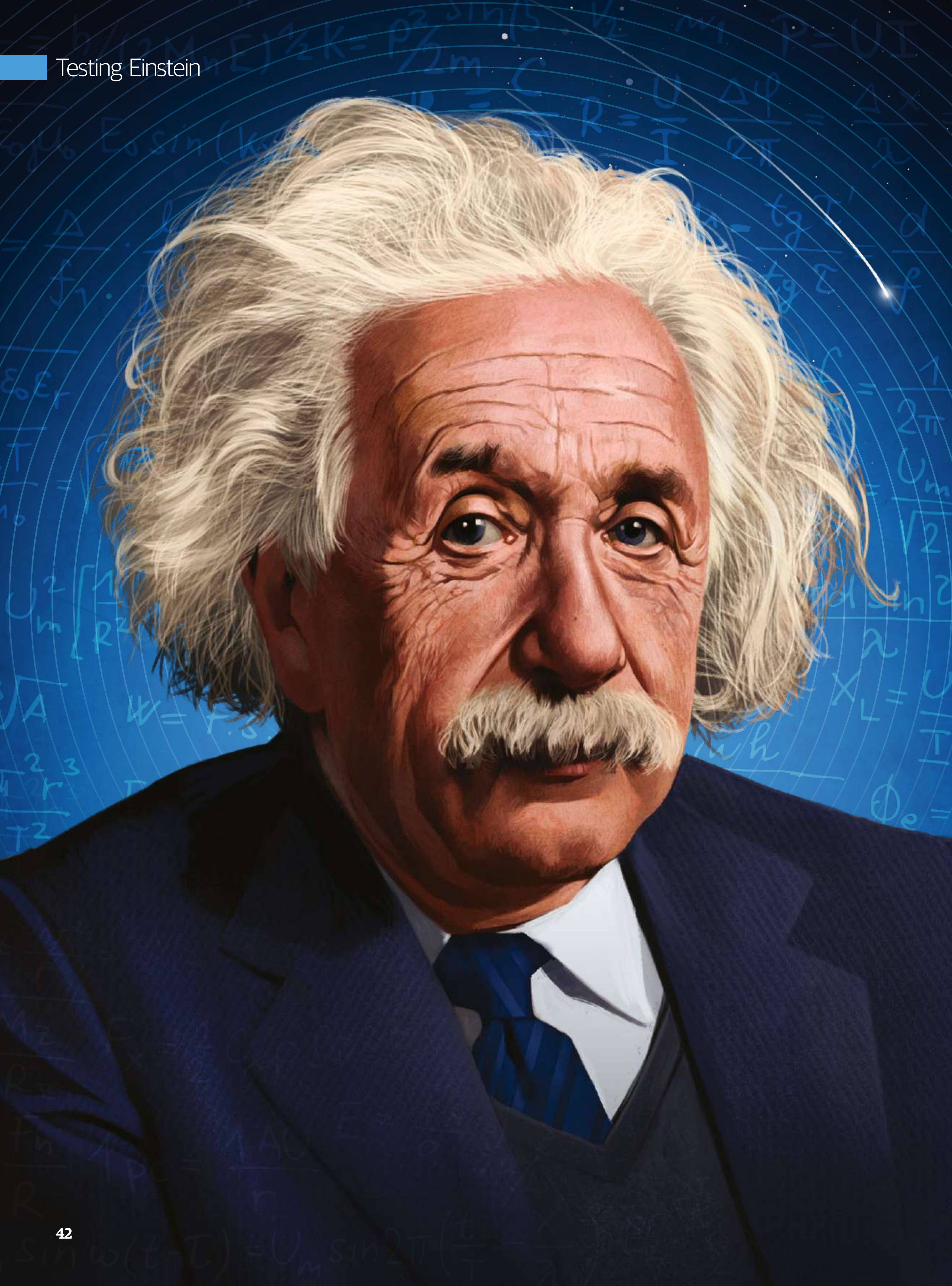


TESTING EINSTEIN

How attempting to break the theory of general relativity has migrated beyond the limits of the Milky Way

Reported by Robert Lea

Testing Einstein's geometric theory of gravity, or general relativity (GR), was never going to be a straightforward task. At the heart of GR are the effects that massive objects such as planets, stars and even entire galaxies cause on the fabric of space. Such tremendous masses aren't easily replicated in the lab, especially before the debut of complex computer simulations. In the century since its introduction, physicists have moved GR experiments into space, out past the limits of the Solar System and even beyond our galaxy.

"Space is the most ideal laboratory for testing general relativity, as its effects in and around the Solar System are so minuscule," Vivek Venkatraman Krishnan, an astrophysicist at the Max Planck Institute for Radio Astronomy, Germany, explains. "The effects of GR are significant only around objects that have strong gravitational fields - such as neutron stars and black holes - which makes them ideal laboratories for testing." During this journey, scientists have studied some of the most powerful and mysterious objects in the universe.

"GR was revolutionary because it jettisoned the Newtonian concept of gravity as an attractive force between massive bodies. It replaced it with the idea that space and time - or space-time - is warped or curved by the presence of massive bodies, and that it is this curvature that leads to the orbital motion of stars and planets and the fall of an apple from a tree," Clifford Will, professor of physics at the University of Florida and author of *Was Einstein Right?* says. "This was a strange and radical conception, and many physicists, especially experimentalists, reacted strongly against it. The main challenge was that the effects predicted in the Solar System were tiny."

Upon its introduction in 1915, Einstein knew that his new theory would have to account for the phenomena of gravity at least as well as Newton's law of universal gravitation, which had served science just fine for over 200 years. But matching its predecessor's level of experimental verification would be a challenge to say the least. To this end, the physicist calculated three tests that could be used to verify his new theory of gravity. The first of these involved doing something Newton's theory couldn't - explaining a strange 'wobble' in the orbit of Mercury.

With each orbit, Mercury's orientation shifts slightly, a movement called perihelion precession. A tiny fraction of this - just 43 seconds of arc per 100 years - couldn't be explained by the influence of

CORRECTING MISTAKES

The original version of Einstein's theory, published in 1913, contained a mathematical miscalculation in the amount a beam of light would bend due to gravity. It was fixed for the 1915 version.

Gravity Probe B's incredible sensitivity allowed it to test GR from an orbit around the Earth

© NASA

HOW DO WE TEST GENERAL RELATIVITY?

Testing the theory often means studying objects of tremendous masses only found in deep space

MEASURING THE EFFECTS OF MASS ON SPACE-TIME

The way objects of tremendous mass 'warp' space-time can have effects on matter and energy that astronomers can see and measure. These effects can be used as a test of general relativity, as well as providing us with vital information about the physics that govern light and matter.

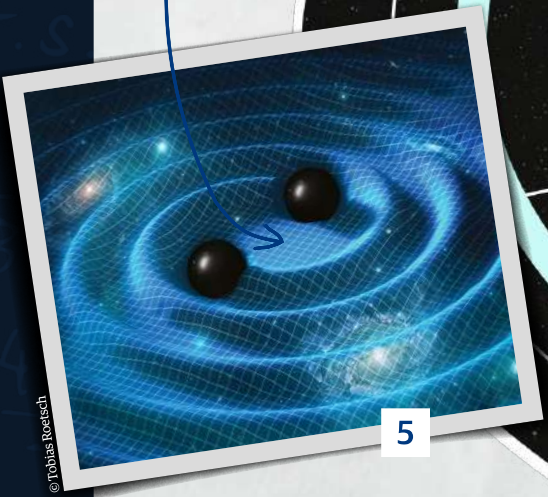
1 GRAVITATIONAL LENSING

Space-time curvature bends light rays, meaning a distant object can appear in a shifted position.

2 EINSTEIN RINGS: GRAVITY'S ILLUSIONS

Gravitational lensing means objects can appear multiple times in the sky.

The Laser Interferometer Gravitational-Wave Observatory is able to detect ripples in space-time caused by collisions



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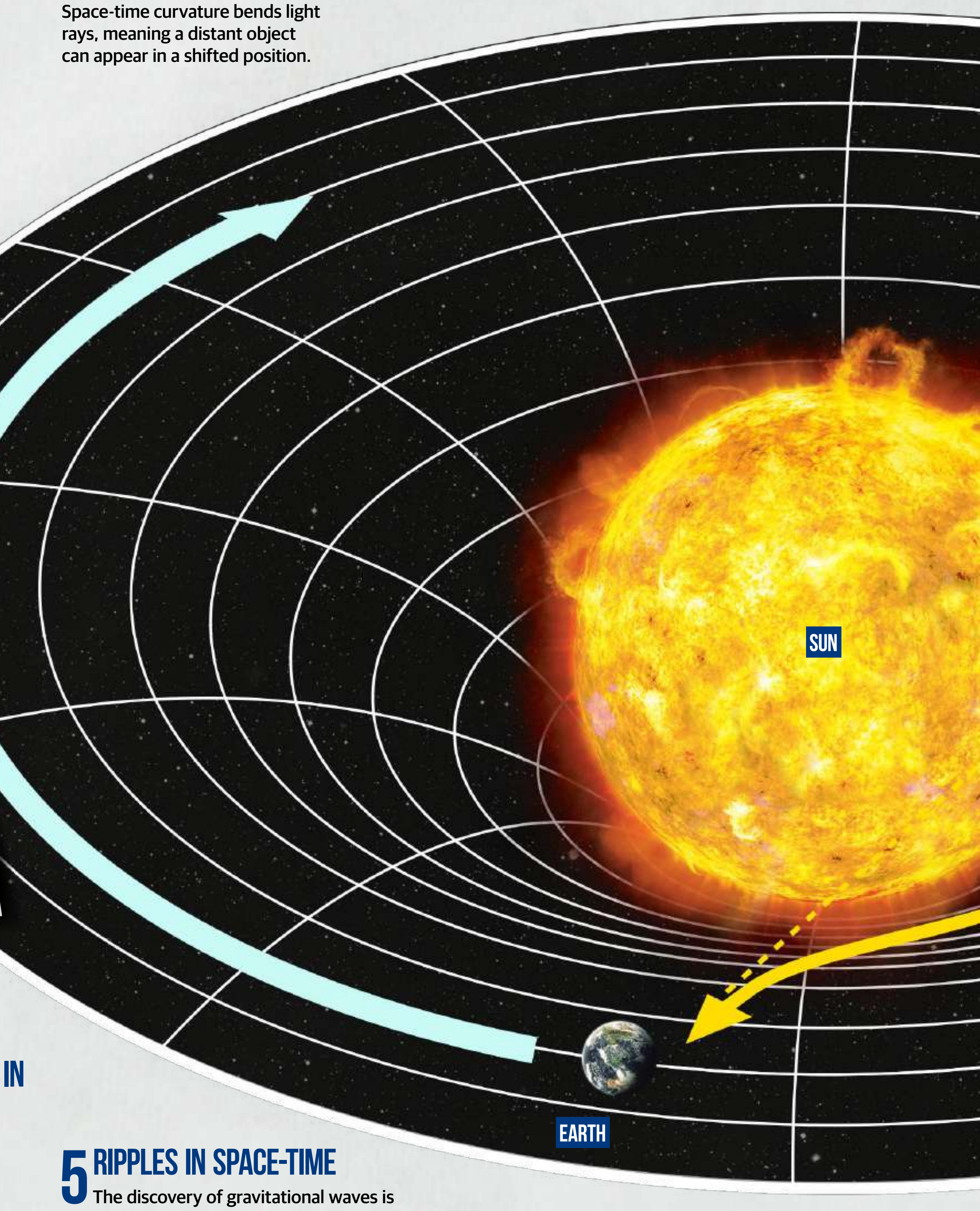

HOW MASS CURVES SPACE-TIME IN GENERAL RELATIVITY

General relativity predicts that mass can cause the curvature of space-time. The greater the mass, the more extreme the curvature. This affects how matter and light move through space.

5 RIPPLES IN SPACE-TIME

The discovery of gravitational waves is possibly the ultimate verification of GR.

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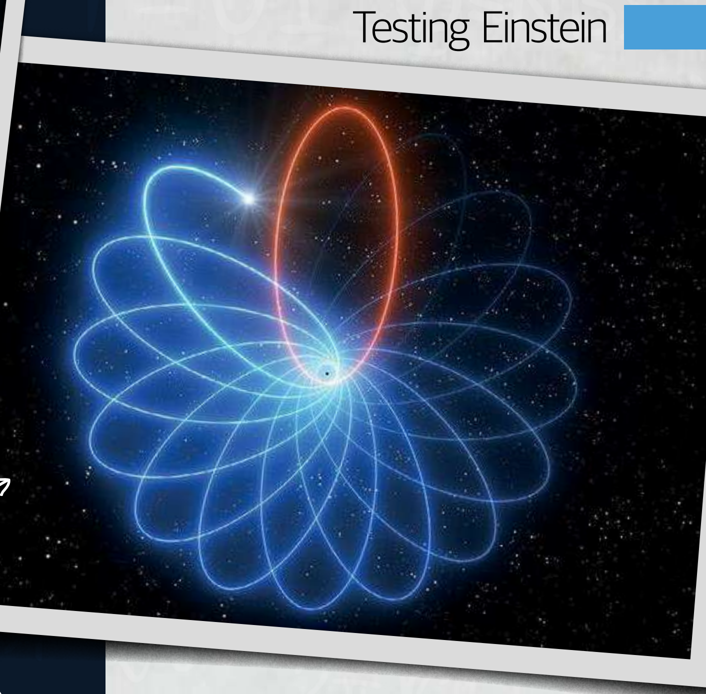
Gravitational lensing by a foreground object can divert light from more distant ones, splitting it into different sections



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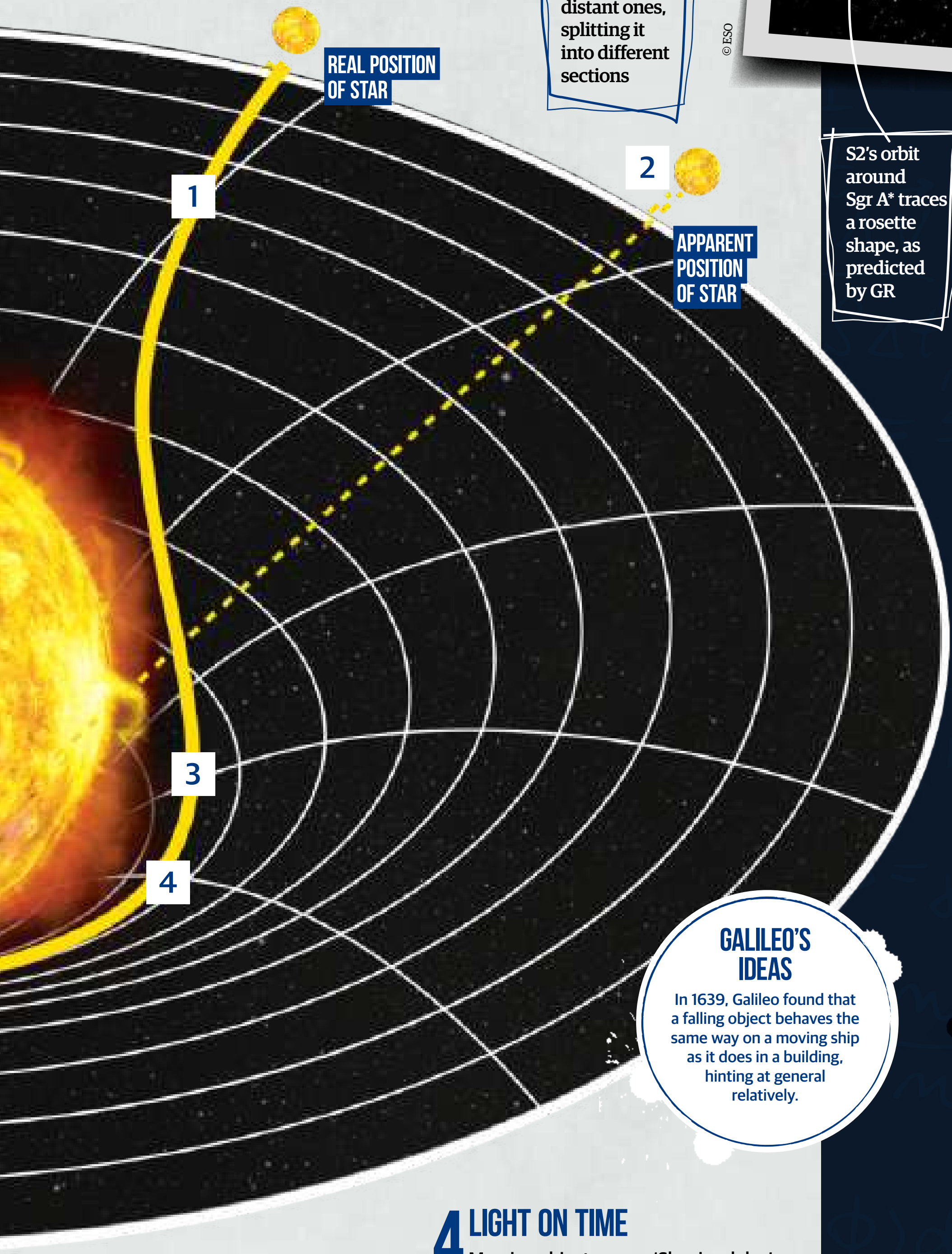
S2's orbit around Sgr A* traces a rosette shape, as predicted by GR

3 SEEING RED: GRAVITATIONAL REDSHIFT

Light's wavelength is 'stretched' towards the red end of the electromagnetic spectrum by the presence of mass.



4 LIGHT ON TIME

Massive objects cause 'Shapiro delay' – a delay in the travel time of light.

GALILEO'S IDEAS

In 1639, Galileo found that a falling object behaves the same way on a moving ship as it does in a building, hinting at general relatively.

other bodies in the Solar System. Einstein used an approximation of the Schwarzschild metric – a solution to the field equations underpinning the theory – to show GR predicted this perfectly.

While this was an important first step on the road to validating GR, the theory would require something bigger if it was to receive the blessing of the scientific community. "GR also predicted that light would be deflected in passing by a massive body. For the Sun, the maximum deflection was only 1.7 arcseconds, so very tiny," says Will, explaining Einstein's second test. "The only way to detect it was during a total solar eclipse."

English astronomer Arthur Eddington, one of GR's early champions, took it upon himself to perform this second test, and he and colleague Frank Watson Dyson saw the solar eclipse of 1919 as the perfect opportunity to do this. During this eclipse the cluster of stars known as the Hyades would sit behind the Sun, with some of its stars visible near the eclipsed disc. This meant that their positions could be recorded and compared to previous records, revealing any apparent shifts caused by the Sun's gravitational influence.

Eddington travelled to the island of Príncipe off the coast of west Africa to collect observations. Combined with data taken from Sobral, Brazil, by a second team, led by Andrew Crommelin from

> "GR JETTISONED THE CONCEPT OF GRAVITY AS AN ATTRACTIVE FORCE" **CLIFFORD WILL**

the Royal Greenwich Observatory, London, results conformed to Einstein's theory. "The announcement of the verification of GR in November 1919 made Einstein an overnight science superstar," says Will.

Despite these initial successes, the testing of GR slowed down after this, only experiencing a renaissance in the mid-20th century when the invention of equipment like radio telescopes shifted study beyond the Solar System. This renewed interest has included confirmation of Einstein's third testing criteria – the discovery of gravitational redshift. "The first test of this effect would not happen until 1960, five years after Einstein's death," Will explains. "Today, of course, the redshift effect on the clocks in GPS satellites must be accounted for, otherwise these global navigation systems would not function properly."

Moving beyond the limits of the Solar System has also made astronomical objects with far greater masses available for testing GR. "The tests of GR done within the Solar System with bodies like Mercury constitute what we call the 'weak field' regime – testing done with 'weakly gravitating' bodies," says Venkatraman Krishnan. "We have entered a brand-new regime – the so-called 'highly dynamical strong-field regime' – testing gravity around strongly gravitating bodies that are also moving at a speed that is a significant fraction of the speed of light, as is the case for colliding neutron stars and black holes that emit gravitational waves."

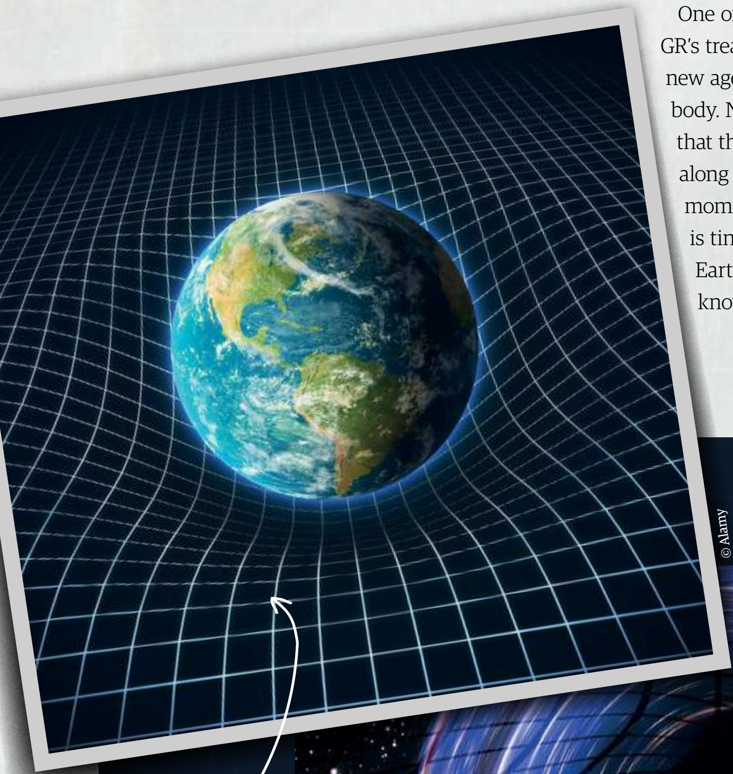
One of the most evocative consequences of GR's treatment of space-time explored in this new age occurs around a massive rotating body. Near a massive object, GR suggests that the fabric of space-time will be dragged along in the direction of the body's angular momentum. This 'frame-dragging' effect is tiny around a relatively small body like Earth. But the phenomenon – officially known as the Lense-Thirring effect – becomes much more extreme and measurable around truly massive cosmic objects like neutron stars and black holes.

"The common analogy that people use is the placement of a small ball in a bowl of honey – akin to a neutron star sitting in space-time. Add a drop of food colouring near the ball. Spin the ball quickly and notice that the honey turns with it. You will see that the ball drags the honey along, just like the rotating neutron star drags space-time," says Venkatraman Krishnan, no stranger to the Lense-Thirring effect.

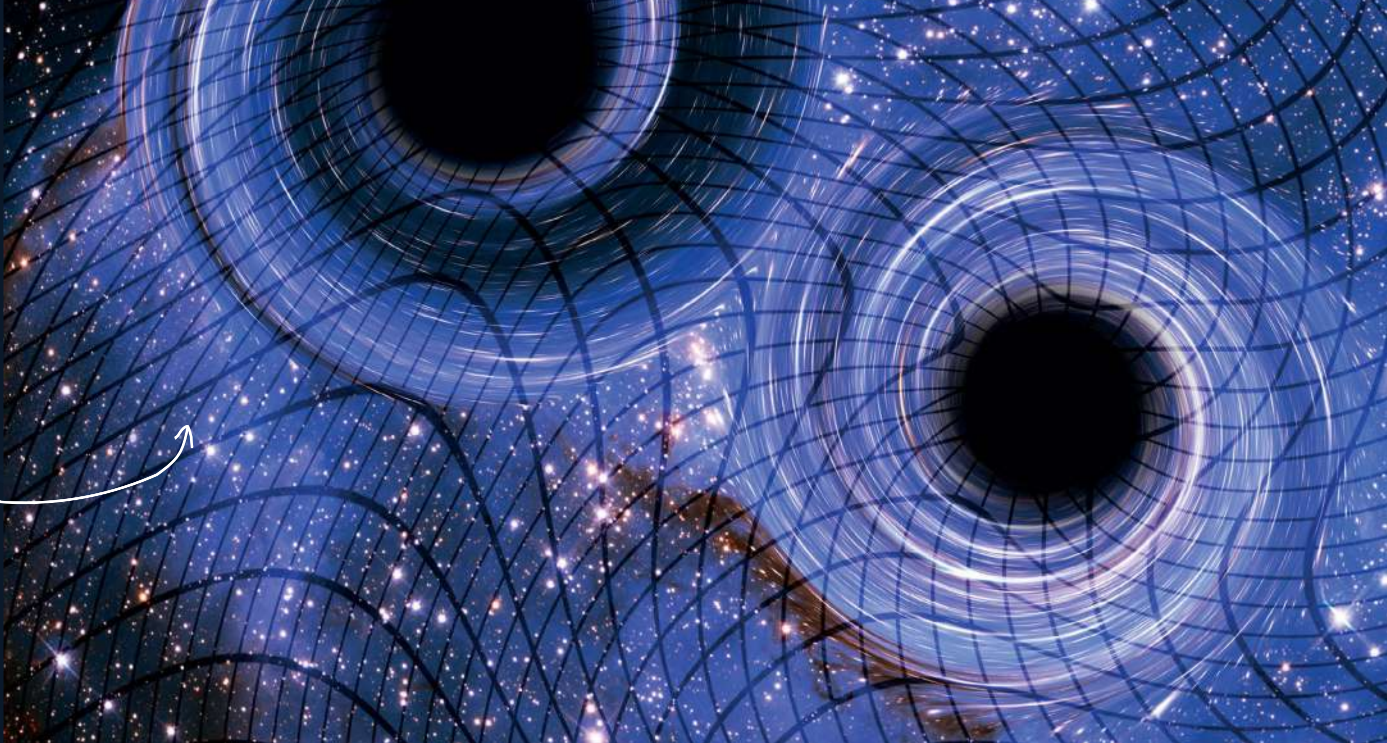
The astrophysicist was part of a team that studied the dragging of space-time around the white dwarf-pulsar binary PSR J1141-6545, located in the constellation of Musca, the Fly. As well as testing GR, the experiment also allowed the team to determine the radius of the system's neutron star. As its mass is already known, this gives the researchers an idea of the density of the object. This should ultimately help researchers gather information about its composition and possibly solve long-standing mysteries about neutron stars such as their mass limits and the composition of their interiors.

WORKING IT OUT AT WORK

Einstein wrote much of his theory during quiet periods working at the Swiss patent office.



One of the most revolutionary aspects of GR was its prediction that mass curves space-time



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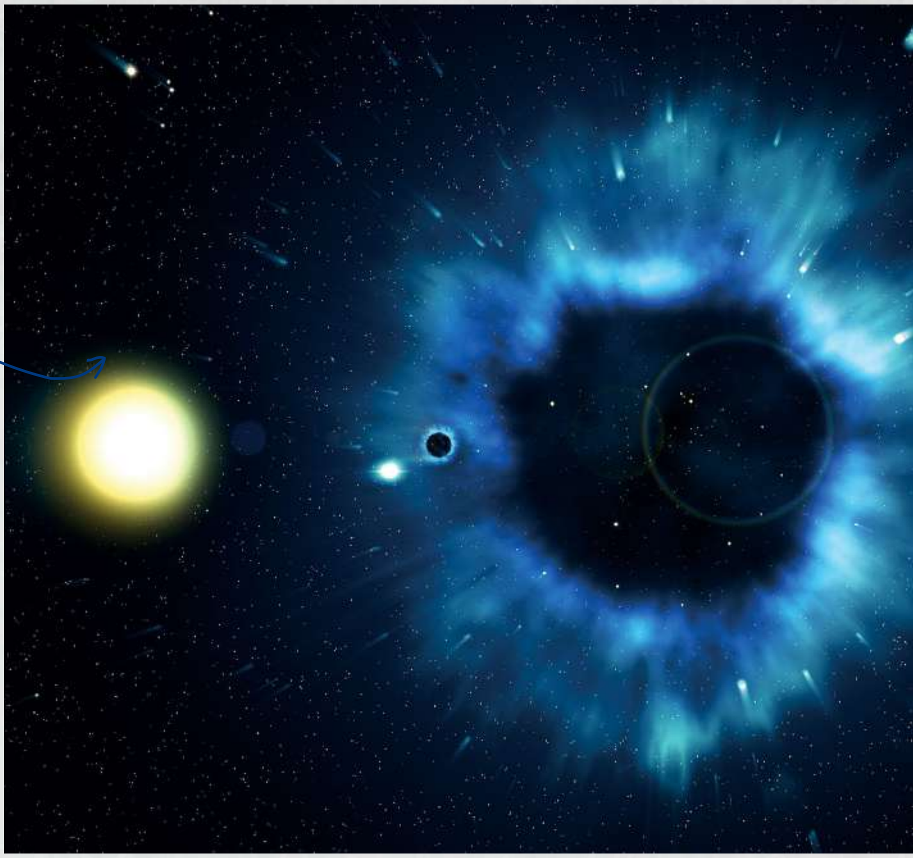
Gravitational waves from distant merging black holes are a strong confirmation of general relativity



GR effects become measurable around massive objects, like this black hole with a supernova companion

© ESA, NASA

It's no great surprise that the testing of GR - a theory of the astronomically massive - has often involved the most compact and massive space-time events possible: black holes. As they first emerged as pure theory from singularities that arose in the mathematical solutions of GR's field equations, it's only right black holes should play a vital role in the testing of the theory. The figurative shadow of the black hole may linger over GR, but it was the literal shadow of a black hole that informed a recent test of Einstein's theory.

The first direct image of a supermassive black hole (SMBH) - the one at the centre of the galaxy Messier 87 released in April 2019 - has inspired this new test of GR. Astronomers at the Event Horizon Telescope (EHT) realised that if Einstein's theory of gravity is correct, the shadow of a SMBH should have specific dimensions. The team used GR to calculate the size of the shadow of M87's SMBH, finding that its image matched these parameters. Once again this verified Einstein's theory - this time using an extragalactic object.

Closer to home - albeit still 26,000 light years away - the SMBH at the centre of the Milky Way, Sagittarius A* (Sgr A*), has played a role in modern GR tests. In 2020, a team of researchers led by Reinhard Genzel, director at the Max Planck Institute for Extraterrestrial Physics, Germany, looked for an effect similar to perihelion precession in the orbit of a star in the proximity of Sgr A*, known as the Schwarzschild precession.

> **"SPACE IS IDEAL FOR TESTING GR; ITS EFFECTS AROUND THE SOLAR SYSTEM ARE SO MINUSCULE" VIVEK VENKATRAMAN KRISHNAN**

© Getty

The team tracked S2 - one of a dense cluster of stars that resides around the bright radio source at the centre of the Milky Way - as it whipped around Sgr A* at a stunning 9 million metres (30 million feet) per second over 30 years. They observed that S2's highly elliptical 16-year orbit displayed the same open nature as that of Mercury, tracing out a rosette shape around the SMBH. Again this matched GR's predictions precisely, as well as confirming that this radio source is indeed a SMBH.

"It completely astonishes me that the theory that we are concerned with testing is precisely the theory that Einstein wrote down in late 1915," exclaims Will. "All of the other fundamental theories of physics have evolved dramatically during the same period. GR hasn't changed one iota, yet it continues to pass every single test with flying colours."

Observing the same effect first measured by Eddington and his team in the orbit of Mercury in a star orbiting a SMBH may figuratively bring GR testing full circle, but that doesn't mean physicists are done testing. The benefits of GR testing have helped unlock the secrets of neutron stars, black holes and space-time itself.

"Einstein himself did not believe several of his predictions would ever be testable. When he lived there were no lasers, and quasars and pulsars were not discovered. Now, thanks in part to GR, we use these inventions and discoveries to understand the universe better," concludes Venkatraman Krishnan. "I think we should keep testing it, pushing its limits - who knows, something entirely unexpected could be waiting to be discovered!"

Robert Lea
Space science reporter
Rob is a science writer with a degree in physics and astronomy. He specialises in physics, astronomy, astrophysics and quantum physics.

Instant expert

WHAT IS THE FERMI PARADOX?

In 1950 the Nobel Prize-winning physicist Enrico Fermi asked: "Where is everybody?" He was referring to extraterrestrial intelligence. Seven decades later, his question remains unanswered. It's a source of continuing debate - and one of the few important scientific questions to which non-experts can contribute. People often refer to his question as a 'paradox' because our observations don't agree with what we might expect to see.

On the one hand, we know there are many potential homes for life: our own galaxy might contain 100 billion planets. If we follow the Copernican principle - that there's nothing special about Earth, and nothing special about humanity - then we might reasonably expect technological intelligence to have evolved many times. The well-known Drake equation lets us estimate the number of extraterrestrial civilisations in the Milky Way.

Any civilisations out there could be hundreds of millions of years older than ours. Imagine a civilisation reaching our level of advancement and then developing its technology for just a few thousand years. Wouldn't that level of technology enable them to disturb the universe in a way we could detect? The colonisation of the galaxy might take them a million years or so - a blink in cosmic terms. They should be here! Even if they choose not to colonise, we might still expect to detect their technosignatures. But the universe appears silent. So where *is* everybody?

For those who believe in flying saucers, Fermi's question has an obvious solution. For many scientists, however, the answer is that they're out there, and an expanded Search for Extraterrestrial Intelligence (SETI) program will find them. But there's another possibility: humans, for some reason of astronomy or biology or chance, are alone in the universe. If ours is indeed the only technological intelligence, then surely we have a duty to ensure its survival?

> "WE KNOW THERE ARE MANY POTENTIAL HOMES FOR LIFE: OUR OWN GALAXY MIGHT CONTAIN 100 BILLION PLANETS"

$$N = R_* \times f_p \times n_e$$

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This represents the number of technologically advanced civilisations in our home galaxy. The more advanced an extraterrestrial civilisation is, the more likely we are able to detect signatures from its technology, such as electromagnetic emissions. If they're really advanced, they might be able to pay us a visit in a futuristic craft.

© NASA, ESA and the Hubble Heritage Team

This is the mean rate of the formation of stars in our galaxy. Leftover material from this process has been shown to coalesce into planets, which may end up being suitable for hosting life. NASA and the European Space Agency (ESA) estimate that seven new stars are born annually in the Milky Way.

The fraction of new stars which form at least one planet from the gas, dust and debris in their protoplanetary disc. Exoplanet-hunting space telescope Kepler discovered that almost all Sun-like stars and the majority of red dwarf stars seem to have planets in orbit, which makes planets quite commonplace.

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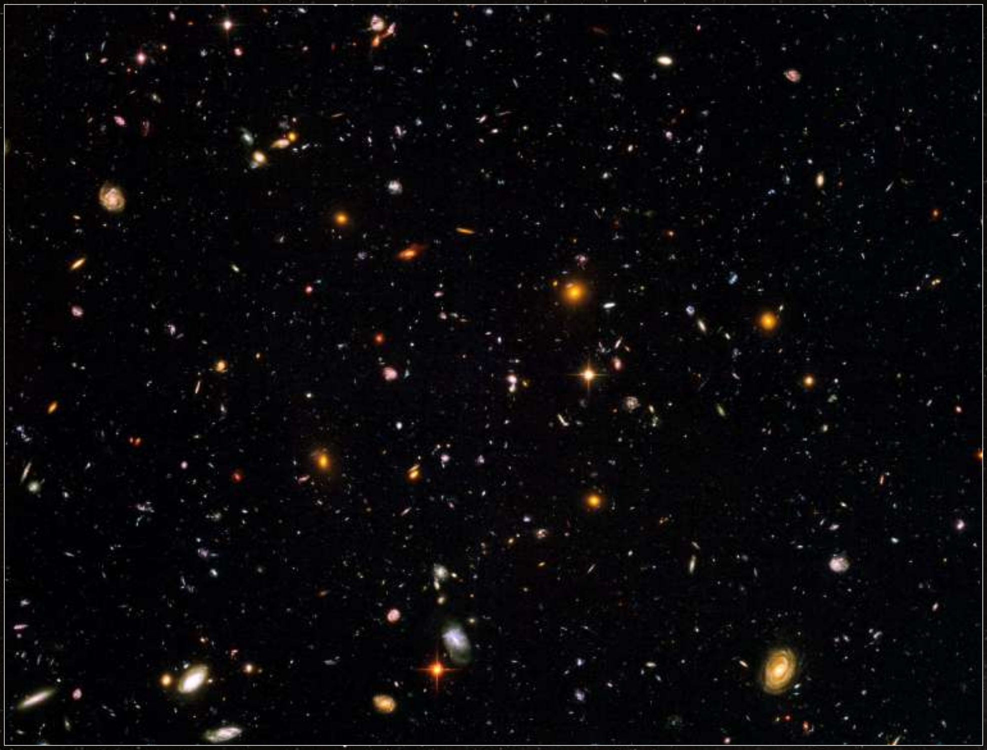
This denotes the number of planets in a solar system capable of allowing life to flourish. Our Solar System has Earth, but there is also evidence that Mars and Venus could host life, or may have in the past. This doesn't take into account any life on moons in orbit around planets which may host them, however.



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Left: Hubble's Ultra Deep Field highlights the astounding number of galaxies that are out there

BIO

STEPHEN WEBB

Dr Webb works at the University of Portsmouth. He is the author of a number of books, including an undergraduate text on the cosmological distance ladder, popular science books exploring the interplay between science and science fiction and the best-selling *Where is Everybody?*, which discusses 75 approaches to the Fermi paradox. His 2018 TED talk 'Where are all the aliens?' has been viewed over 5.6 million times.

$$f_l \quad \times \quad f_i \quad \times \quad f_c \quad \times \quad L$$

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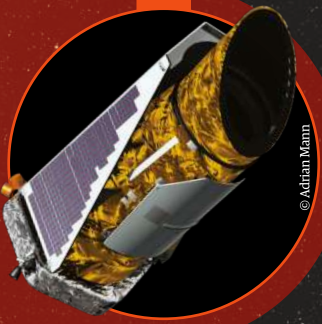
Although a planet may have all the necessary building blocks for life to evolve, it's not guaranteed. This part of the equation marks the number of planets on which life actually appears, even in its simplest forms. So far we only know of one planet that has managed to get to this stage, with microbial life first evolving on Earth 3.7 million years ago.

© Getty

This is the fraction of planets with intelligent life. Life has existed on Earth for approximately 3.7 billion years, but our earliest ancestors can be traced back just 200,000 years. And it's only in the last few thousand years we've become a truly intelligent species. Other life may not quite be there yet – or could have gone extinct before reaching this threshold.



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It's only been 60 years since humanity entered the Space Age, and we didn't send out our first message – Arecibo – until 1974. If an alien civilisation isn't yet advanced enough to send out a detectable signal, we're very unlikely to notice them, even from one star system away. This represents the fraction of civilisations able to do so.

This is the amount of time over which signals are sent out. Since our first radio broadcast into the cosmos, we've sent out many more signals and messages in different ways. Over 50 years this has added up to many signs of life that someone out there could take notice of, and even allows them time to reply if they're not too distant.

A NEW VIEW OF THE MILKY WAY

A DYNAMIC, COMPLICATED, BUBBLE-BLOWING WILD CHILD: MEET OUR GALAXY ALL OVER AGAIN

Reported by Kulvinder Singh Chadha

Like a baby, our galaxy ate a lot and grew big. And like a person it's constantly changing. Work done by many astronomers shows its all-consuming past, while new results from the European Space Agency's (ESA) Gaia spacecraft show its complex dynamics. Alongside this are new observations of the galaxy we call home.

The popular view of the Milky Way is that it's a spiral galaxy with arms of stars, dust and gas radiating out in a disc around 120,000 light years across, with a central galactic bulge 10 to 12,000 light years in diameter. Our Solar System lies 26,000 light years from the Galactic Centre - between the bulge and the disc edge. Yet there are more elements to the galaxy's structure than this. Spitzer Space Telescope observations in 2005 showed that the Milky Way is a barred spiral - its central region is bar-shaped. And the galaxy is peppered by a spheroidal halo of globular clusters.

Around 150 in total, these are gravitationally bound formations containing hundreds of thousands of very old stars. The Milky Way also has numerous satellite galaxies, some of which are merging with it, while others are having their gas stripped by its gravity. Then there's the bubbles - or lobes - that emanate from the Galactic Centre and the galaxy's large dark matter halo.

Many ancient observers conjectured that the Milky Way was composed of a large number of

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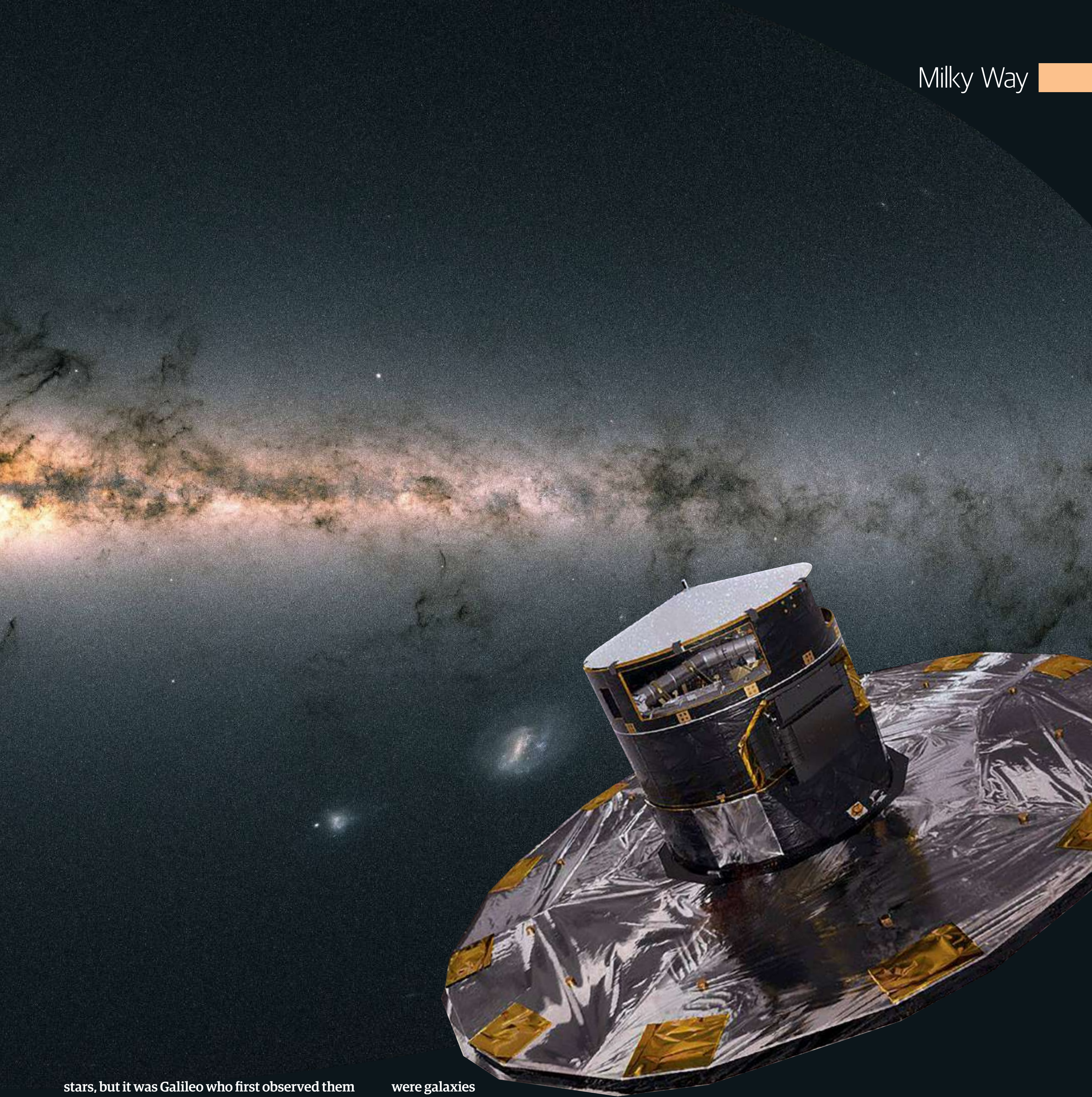


stars, but it was Galileo who first observed them in detail in 1610, using his telescope. 18th-century English astronomer Thomas Wright described our view of the Milky Way as an 'optical effect' due to our position in a flat layer of stars. His German contemporary Immanuel Kant further elaborated that the Milky Way was a rotating disc of stars.

In 1785 William Herschel tried to discern the Milky Way's shape by mapping the stars within. But right up until the 20th century, many scientists thought that the Milky Way was the entire universe. Advances in astronomical observation showed them this wasn't so. Dubbed 'island universes' by Kant, American astronomer Edwin Hubble found in 1924 that many nebulae were galaxies in their own right.

It was apparent that the Milky Way was a galaxy among galaxies, and from others its shape and structure could be inferred. Wright, Kant and Herschel were on the right lines. Our knowledge of the Milky Way's formation history, however, has been somewhat weaker.

The two main theories of galaxy formation are dust and gas collapsing into a disc with a central bulge, much like what happens with solar systems, but on a much larger scale, and smaller structures coalescing into a larger galaxy. But with little conclusive evidence, astronomers can't decide which scenario is correct.

> "WE DON'T NEED SIMULATIONS TO PREDICT THE MILKY WAY'S FUTURE. OBSERVATIONS CAN TELL US MUCH MORE"
>
> DIEDERIK KRUIJSSEN

© NASA

However, that may have changed. Like forensic experts, Dr Diederik Kruijssen of Heidelberg University's Center for Astronomy, Dr Joel Pfeffer of Liverpool John Moores University and others have reconstructed the Milky Way's youthful years using nothing more than the unassuming globular clusters that pepper the halo. To achieve this they used a dedicated computer model called E-MOSAICS to simulate the formation of a Milky Way-like galaxy via the mergers of smaller progenitors. Importantly, the model had the resolution required to simulate the complete evolution of globular clusters. But on its own this wouldn't be enough. As Kruijssen says, galaxy assembly is extremely messy, with globular clusters' orbits getting completely reshuffled. Imagine trying to unmix the cream in a coffee; that's the kind of problem they had. Their investigation needed turbocharging.

So the team turned to artificial intelligence. They trained a neural network on the simulations, paying particular attention to how globular cluster properties related to galaxy formation history. They then tested the neural network against E-MOSAICS, tens of thousands of times. The AI had accurately figured out how to reconstruct the mergers using globular cluster data alone. It was time for a real-world test.

Using the Milky Way's globular clusters grouped via their ages, metallicities and chemical compositions and orbital motions, they fed the data into the neural network. The AI successfully deduced the stellar masses and merger times of the progenitor galaxies that comprise the Milky Way. But there was something else. It discovered something that no human had seen before: a previously unknown progenitor, which the scientists called 'the Kraken'. The AI showed that the Kraken had merged with the nascent Milky Way in its early years, when it was a quarter of its current size, some 11 billion years ago. Of all the progenitors, this had the most profound effect on

MILKY WAY BY NUMBERS

1.9 MILLION

The Milky Way's diameter in light years, when accounting for its dark matter halo

115KM

Annual deflection in the Solar System's trajectory as it orbits the galaxy

59

Number of known satellite galaxies of the Milky Way, at the time of writing

1.5 TRILLION SOLAR MASSES

The Milky Way's mass within a radius of 129,000 light years of the Galactic Centre

150

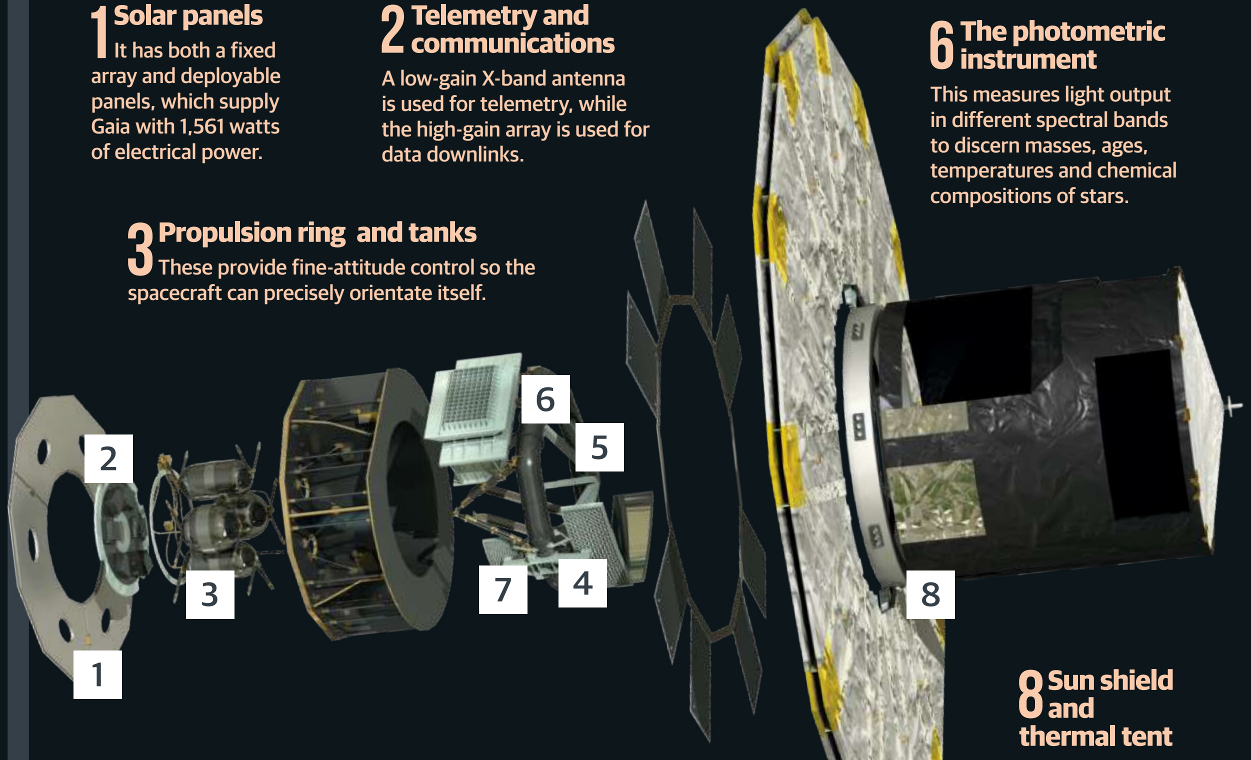
The number of globular clusters that populate the Milky Way's spheroidal halo

300 MILLION

The potential number of habitable planets in the Milky Way, as of November 2020

THE GAIA SPACECRAFT

Gaia will target each object 70 times, making the most accurate 3D Milky Way map ever



© Adrian Mann

1 Solar panels It has both a fixed array and deployable panels, which supply Gaia with 1,561 watts of electrical power.

2 Telemetry and communications A low-gain X-band antenna is used for telemetry, while the high-gain array is used for data downlinks.

3 Propulsion ring and tanks These provide fine-attitude control so the spacecraft can precisely orientate itself.

4 Payload module optical bench Two telescopes with three mirrors each look out in different directions before merging their optical paths.

5 The astrometric instrument Dubbed Astro, this combines the views of Gaia's twin telescopes to obtain the positions of objects.

6 The photometric instrument This measures light output in different spectral bands to discern masses, ages, temperatures and chemical compositions of stars.

7 Radial Velocity Spectrometer Obtains line-of-sight velocities from the spectra of mostly G and K-type stars in near-Infrared.

8 Sun shield and thermal tent The Sun shield maintains Gaia at a stable temperature while the tent protects from micrometeorites and radiation.

our galaxy's later development. Over the next 5 billion years the galaxies of the Helmi stream, Sequoia, Gaia-Enceladus and Sagittarius Dwarf would coalesce with ours.

Sagittarius in particular has cropped up in the observations of the Gaia spacecraft, an astrometry mission that's studied 1.8 billion objects in three dimensions, both within and beyond the Milky Way. Do Gaia's latest findings correlate with the team's work? "Yes, our results are consistent," says Kruijssen. "We find that Sagittarius collided with the Milky Way about 6 billion years ago. But such collisions have long durations, of several billion years. At this time the core is still merging with the Milky Way, whereas its outer layers have already been shredded by the Milky Way's gravitational pull." He further adds that if the unexpected stellar motions are caused by Sagittarius, it would be consistent with their finding that Sagittarius is the Milky Way's most recent merger.

This is something echoed by Gaia research scientist Dr Teresa Antoja of the University of Barcelona. Gaia data-processing scientists had previously found a faint ripple among millions of star movements, suggesting a disturbance of the Milky Way's disc. As Antoja says: "The current ripples and velocity disturbances we see could well be produced by Sagittarius, the most recent event mentioned in that study."

Suspected to be part of the Sagittarius merger are both a fast and slow-moving stream of stars, both heading towards the galactic plane. How does such a thing arise? Antoja admits that the answer is unknown. "The pattern we see is very complex - it seems to involve all coordinates of phase space," she explains. "In the coming months we're going to look into simulations of the Sagittarius encounter to see whether similar disturbances are produced." Her team surmises that the fast and slow streams could be an overlapping of different disc waves.

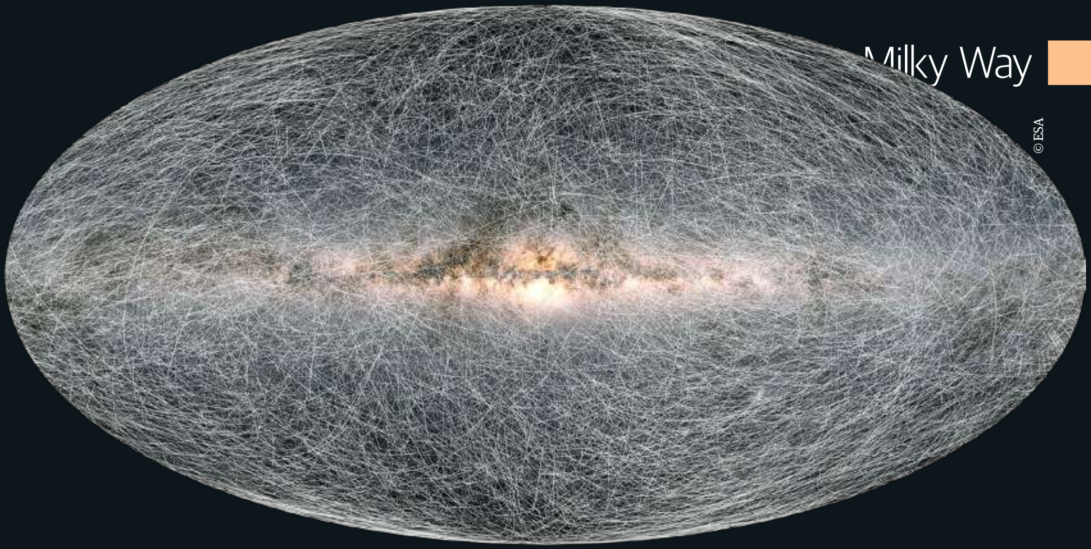
Other surprises in the Gaia data that Antoja highlights are the large observed asymmetry of stars above and below the outer part of the disc, and also the presence of stars orbiting the Galactic Centre at around 60,000 light years, hinting at a larger disc. There's also a few open clusters on disc-like orbits. "We don't know if they were born there or brought there by some dynamical mechanism, or if there are other disc stars at these locations. This needs to be investigated."

Antoja says that her team are also studying the accretion of Gaia-Enceladus, whose individual stars can be identified in the Sun's vicinity, and also in the direction of the anti-centre, the point directly opposite the Galactic Centre, towards the disc edge. They conclude that those stars spread over large distances, mixing with stars born in the Milky Way itself and indicating the significance of that particular merger. Commenting on the teams' different approaches, Antoja says: "It's excellent that we all study this from different viewpoints."

With help from colleagues, Professor Stefan Jordan of Heidelberg University and Dr Anthony Brown of the University of Leiden created an animation that includes some of those nearby stars. There are 40,000 in total, all within 326 light years of the Sun. It follows the motions of the randomly selected stars in three-dimensional space for 1.6 million years, although the animation itself stops after 400,000 years, showing the Sun's drift through the galaxy.

Could such an exercise reveal further clues about the galaxy's merger history? Brown is quick to pour water on that idea. "The animation is only intended to illustrate that we can map stellar motions and predict their positions into the future. It has no relevance for investigations into the merger history of the Milky Way," he says. He adds that that kind of work requires a proper scientific analysis undertaken by many astronomers over the coming months and years.

Conversely, could the AI of Kruijssen and Pfeffer's team show what might happen in the Milky Way's future? Possibly. "We stopped running the simulations when they reached the present day, so we haven't looked at that," Kruijssen admits. "However, we don't need the simulations to predict the Milky Way's future. Observations can tell us much more." He points to the examples of the Milky Way interacting



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RESULTS FROM GAIA

Gaia's latest data release in 2020 revealed a few things never seen before

Updated star map

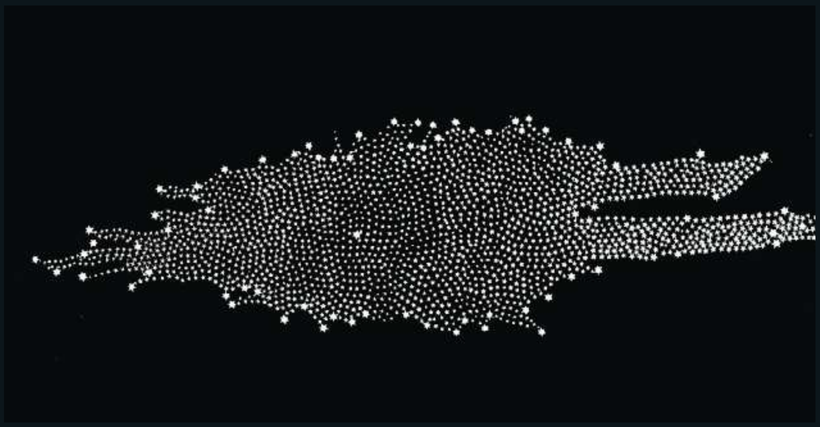
The latest view of the sky from Gaia adds 100 million objects to its previous star map of April 2018, taking the total to 1.8 billion. This represents 0.45 to 1.8 per cent of the Milky Way's total. Visible just below the Galactic Centre, in the middle, is the hint of the Sagittarius Dwarf.

Our garden galaxy

Like a garden or other ecosystem, the galaxy goes through a constant process of renewal. Looking at the anti-centre, Gaia's latest data allowed astronomers to see relics of the Milky Way's 10 billion-year-old ancient disc and determine its smaller size compared to the current disc size.

Knowing our neighbours

Not all the stars in the solar neighbourhood are known. Gaia's has allowed a new stellar census since the 1957 Gliese survey. The Gaia Catalogue of Nearby Stars contains 331,312 objects - estimated to be 92 per cent of the stars within 326 light years of the Sun.

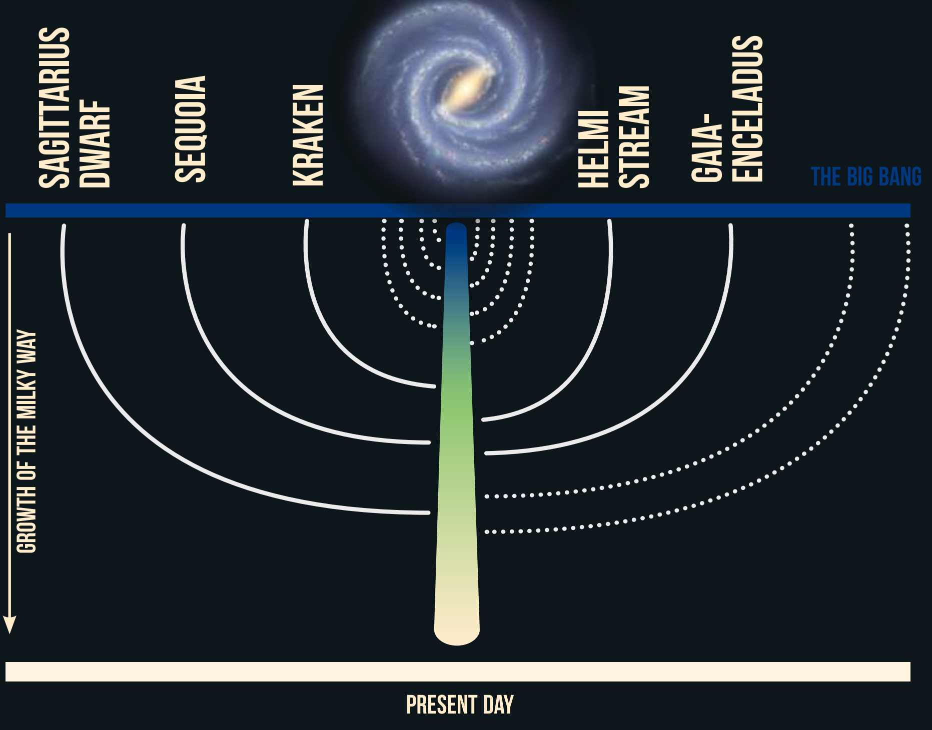


Right: Herschel's hand-drawn map of the stars in the Milky Way, from 1785

© William Herschel

OUR MILKY WAY'S NEW FAMILY TREE

Starting as a collection of clusters, the Milky Way consumed its neighbours



with the Large and Small Magellanic Clouds, as well as its collision with the Andromeda Galaxy – currently approaching us at 100 kilometres (62 miles) per second – in about 4.5 billion years. However, the model is being applied to other galaxies. As Kruijssen says: "This is something we're currently working on. The problem with other galaxies is that we have far less knowledge of their globular clusters." With other galaxies, masses and chemical compositions can be gleaned, but there are large uncertainties in their ages. Velocities can also only be measured for those galaxies orientated along the line of sight. These gaps in data make the exercise challenging.

Aside from the dynamic mergers, another mysterious aspect of the Milky Way are its extragalactic lobes. First spotted by NASA's Fermi Gamma-ray Space Telescope in 2010, these twin bubbles – dubbed 'Fermi bubbles' – are thought to be shock fronts of superheated gas and seemingly emanate from the Galactic Centre, spanning 25,000 light years each above and below the galactic plane. Their origin isn't known, but may be due to cosmic jets from the central supermassive black hole or gas outflows from star formation bursts, both of which would have happened early in the Milky Way's history.

In their latest work, a team from Germany, Russia and Italy saw hints of another, larger set of bubbles. This latest observation, from the joint Russian-German Spektr-RG X-ray space telescope, raises more questions than it answers. Called eROSITA bubbles after the instrument that detected them, these are thought to span 45,000 light years each. Were the eROSITA bubbles like the Fermi ones in the past? As lead scientist Dr Peter Predehl of the Max Planck Institute says: "This is still under discussion. Either yes because there have been two independent events, or one event with both bubbles being linked." The team calculated the energy of the underlying event to be 10^{49} joules – equivalent to 100,000 Type II supernovae. The team is tentatively planning follow-up work. Even though we've uncovered more about the Milky Way than ever, there are many more mysteries waiting to be found.

Kulvinder Singh Chadha
Space science writer
Kulvinder is a freelance science writer, outreach worker and former assistant editor of *Astronomy Now*. He holds a degree in astrophysics.

Right: The eROSITA instrument on board the Spektr-RG spacecraft is what found the new galactic bubbles

Source: Wikipedia Commons © DLR German Aerospace Center

COLLISIONS OF THE MILKY WAY

The galaxy is constantly colliding with its neighbours – something that'll continue far into the future

11 BILLION YEARS AGO

Kraken accretion

Discovered using an AI algorithm, Kraken is the earliest known major merger with our nascent Milky Way. It contributed 13 globular clusters and profoundly affected our galaxy's characteristics from then on.

10 BILLION YEARS AGO

Helmi stream merger

This stream of old stars, around 52,000 light years away in the halo, was once a dwarf galaxy that was disrupted by the ever-growing Milky Way's gravity.

9 BILLION YEARS AGO

Gaia-Enceladus merger

Before Kraken, Gaia-Enceladus was the largest known merger contributing eight globular clusters. Its stars have highly elongated orbits around the Galactic Centre, reaching 65,000 light years.

6 TO 8 BILLION YEARS AGO

Sagittarius encounter

Since its first encounter, Sagittarius has collided with the Milky Way several times. It orbits the Galactic Centre at 50,000 light years, sitting perpendicular to the disc.

1.6 TO 3.6 BILLION YEARS

Large Magellanic Cloud

The Milky Way's gravity is pulling the Large Magellanic Cloud towards a collision that will happen in the next few billion years, throwing its stars into the halo.

4.5 TO 5.8 BILLION YEARS

Andromeda collision

Travelling at 100 kilometres (62 miles) per second, the closest large galaxy to us – Andromeda – will collide with the Milky Way to become a single elliptical galaxy.

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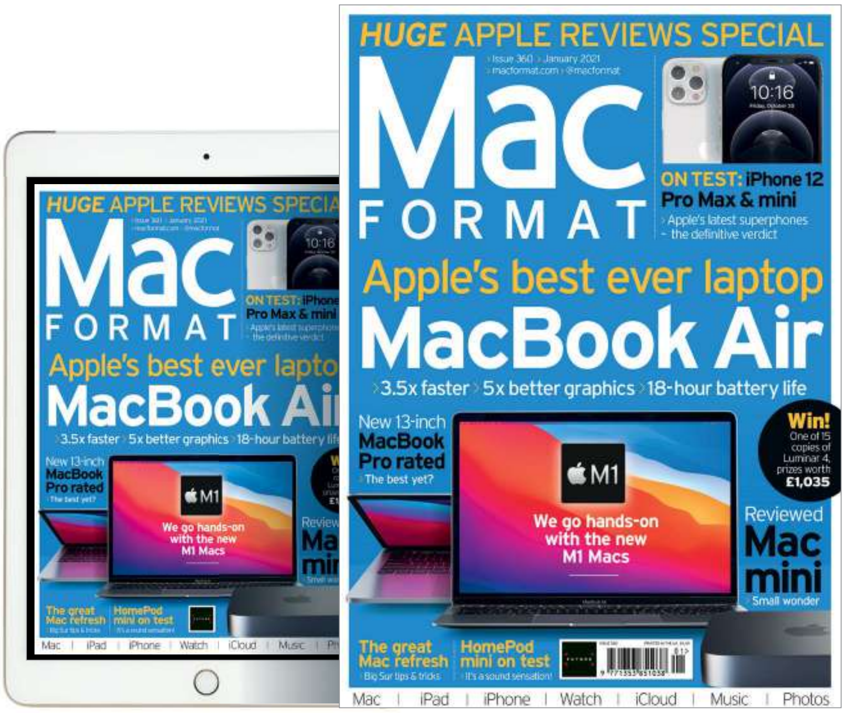

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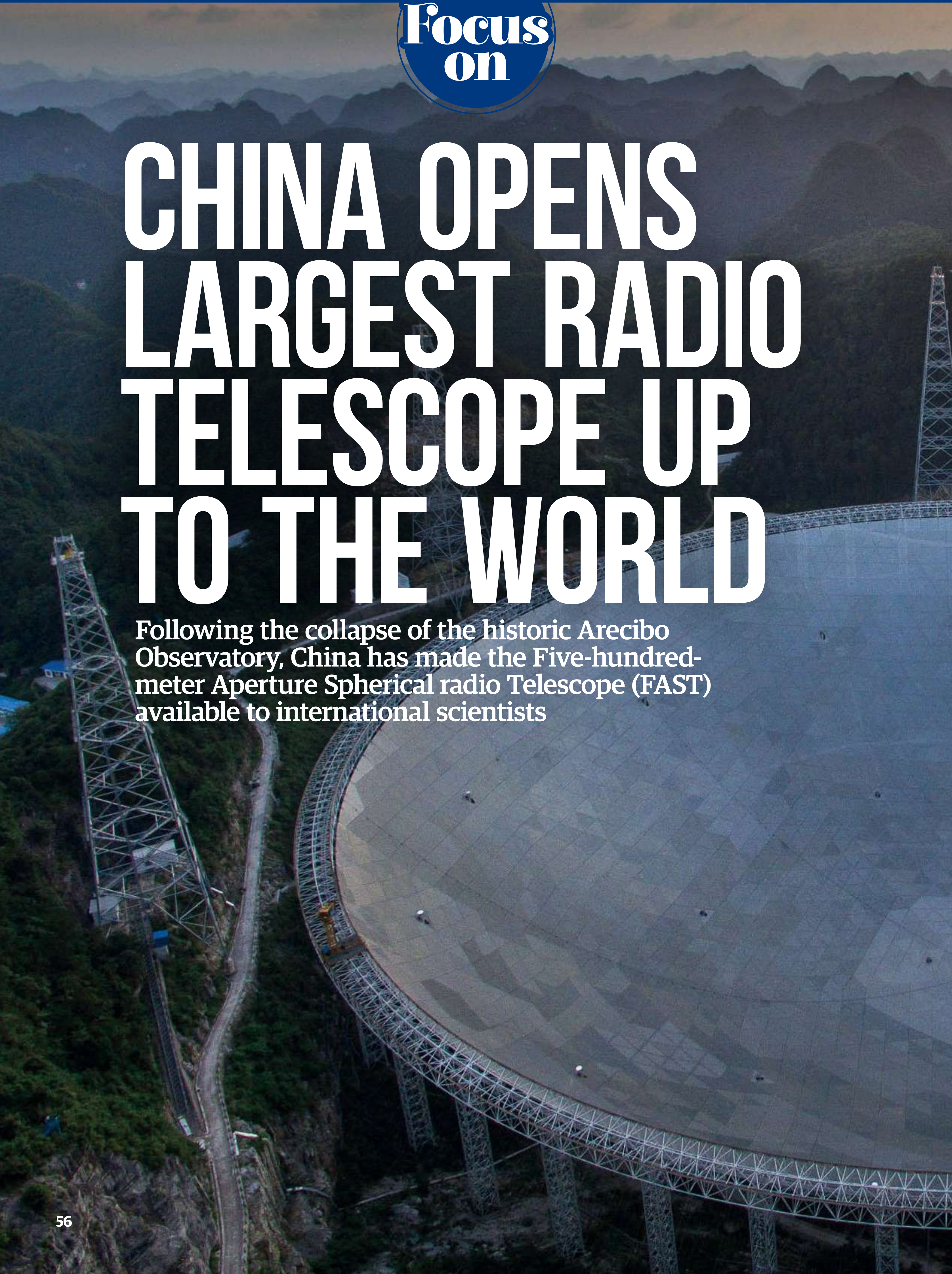

CHINA OPENS LARGEST RADIO TELESCOPE UP TO THE WORLD

Following the collapse of the historic Arecibo Observatory, China has made the Five-hundred-meter Aperture Spherical radio Telescope (FAST) available to international scientists

In Pingtang County, Guizhou, stands the Five-hundred-meter Aperture Spherical Telescope (FAST), the largest radio telescope in the world, surpassing the Arecibo Observatory, which stood as the largest in the world for 53 years before the construction of FAST was completed in 2016.

Following two cable failures earlier in 2020, Arecibo's radio telescope collapsed in November, shutting down the observatory for good. Now FAST is opening its doors to astronomers from around the world.

"Our scientific committee aims to make FAST increasingly open to the international community," Wang Qiming, the chief inspector of FAST's operations and development centre, said. China will accept requests in 2021 from foreign scientists looking to use the instrument for their research.

With its massive dish, which is 500 metres (1,600 feet) in diameter, FAST is not only larger than the now-destroyed Arecibo telescope, but it's also three-times more sensitive. FAST, which began full operations in January of 2020 – though it received 'first light' back in 2016 – is also surrounded by a five-kilometre (three-mile) 'radio silence' zone in which mobile phones and computers are not allowed. "We drew a lot of inspiration from its [Arecibo's] structure, which we gradually improved to build our telescope," Qiming said.

Radio telescopes like FAST use antennae and radio receivers to detect radio waves from radio sources in the cosmos, like stars, galaxies and black holes. These instruments can also be used to send out radio signals and even reflect radio light from objects in the Solar System to see what information might bounce back.

Researchers may use FAST not just to explore the universe, but also to study alien worlds, determining whether or not they rest in the 'goldilocks zone' near their host star, where the existence of liquid water is viable, and also search for alien life.

Famously, in 1974 at Arecibo, scientists working on the Search for Extraterrestrial Intelligence, or SETI, sent out an interstellar radio message to the globular cluster Messier 13 in Hercules in the hopes of receiving confirmation of intelligent extraterrestrial life. The message was coauthored by astronomer and science communicator Carl Sagan, helping to popularise Arecibo and radio astronomy.

Main: The huge dish is able to detect signals from radio sources such as stars and black holes

"OUR SCIENTIFIC COMMITTEE AIMS TO MAKE FAST INCREASINGLY OPEN TO THE INTERNATIONAL COMMUNITY" WANG QIMING

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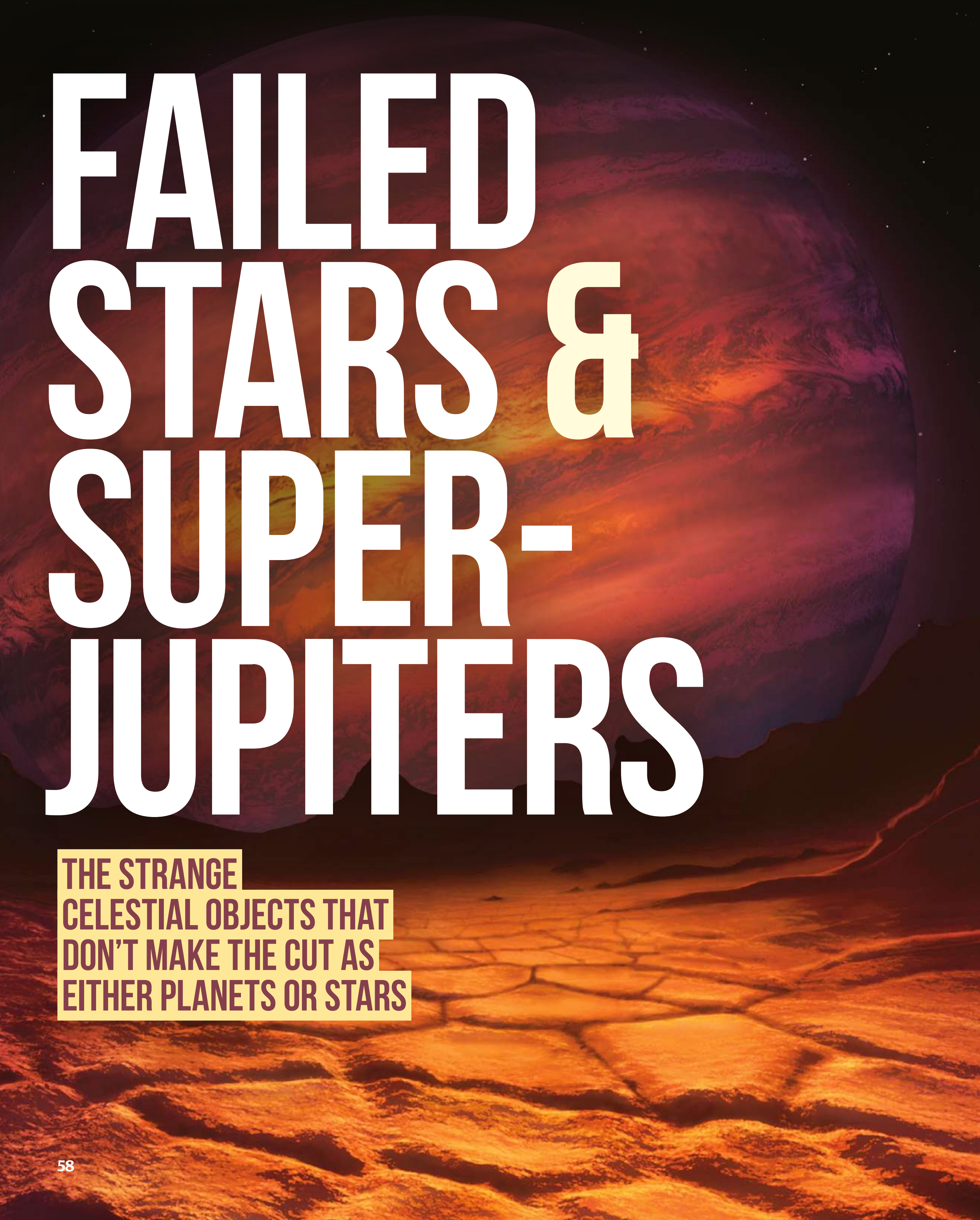


FAILED STARS & SUPER-JUPITERS

THE STRANGE CELESTIAL OBJECTS THAT DON'T MAKE THE CUT AS EITHER PLANETS OR STARS

The brown dwarf is seen as a stellar failure, a dropout from the school of star formation. These gigantic objects, with their puffy, gaseous outer layers, are the universe's students that didn't quite make the grade. In brown dwarfs, nuclear fusion - the process that gives stars their power - has given up the ghost, leaving them relatively cold, with some no hotter than the human body. Neither planet nor star, brown dwarfs fall into the grey area between the most massive gas giant planets like Jupiter - hence why they're known as 'super-Jupiters', because of their massive, gaseous nature - and the smallest stars. Their existence blurs the lines between what is a planet and what is a star, forcing us to question the differences between how planets and stars form.

Stars form when clouds of molecular gas collapse under gravity and condense until the pressure and temperature at the centre of the cloud is so great that nuclear fusion reactions - which turn nuclei of the element hydrogen into heavier helium nuclei - ignite. This kind of top-down formation is one of the key differences between how stars and planets form. Meanwhile, the worlds of our Solar System and many others that astronomers have been studying over the past 25 years form through a bottom-up process, where a core gradually builds up, becoming bigger and bigger. For the most massive planets, the core has enough gravity to begin stealing gas from the proto-stellar nebula around it, and this is where gas giants such as Jupiter and Saturn got their hefty atmospheres.

Brown dwarfs form like stars, collapsing directly out of a gas cloud like a star in a top-down process. Clearly they are intended to become stars, but something happens along the way that causes them to become runts of the stellar litter, smaller and cooler than even chilled-out red dwarf stars.

The universe actually seems to favour smaller objects. The so-called mass function describes the distribution of masses of the objects that are created in a star-forming nebula. A handful will be massive stars that will one day die as supernovae. More will be Sun-like stars. Even more will be red dwarfs, smaller and cooler than our Sun. And the most common type of object that will form in a nebula will be brown dwarfs. This is backed up by observations with the Hubble Space Telescope of the Orion Nebula, which discovered 50 brown dwarfs amid the newborn stars of the Trapezium Cluster. There will undoubtedly be more brown dwarfs in the Orion Nebula, but they are difficult to spot because they are so cool and dim. Hubble used its near-infrared camera to find the brown dwarfs - at their low temperature, brown dwarfs give out most of their light in thermal infrared.

In fact, so difficult are they to spot that the first brown dwarf wasn't discovered until the late-1980s, when astronomers Ben Zuckerman and Eric Becklin of the University of California, Los Angeles, found a suspected brown dwarf called GD 165B - although there remains some lingering doubt that it could just be a very low-mass star.

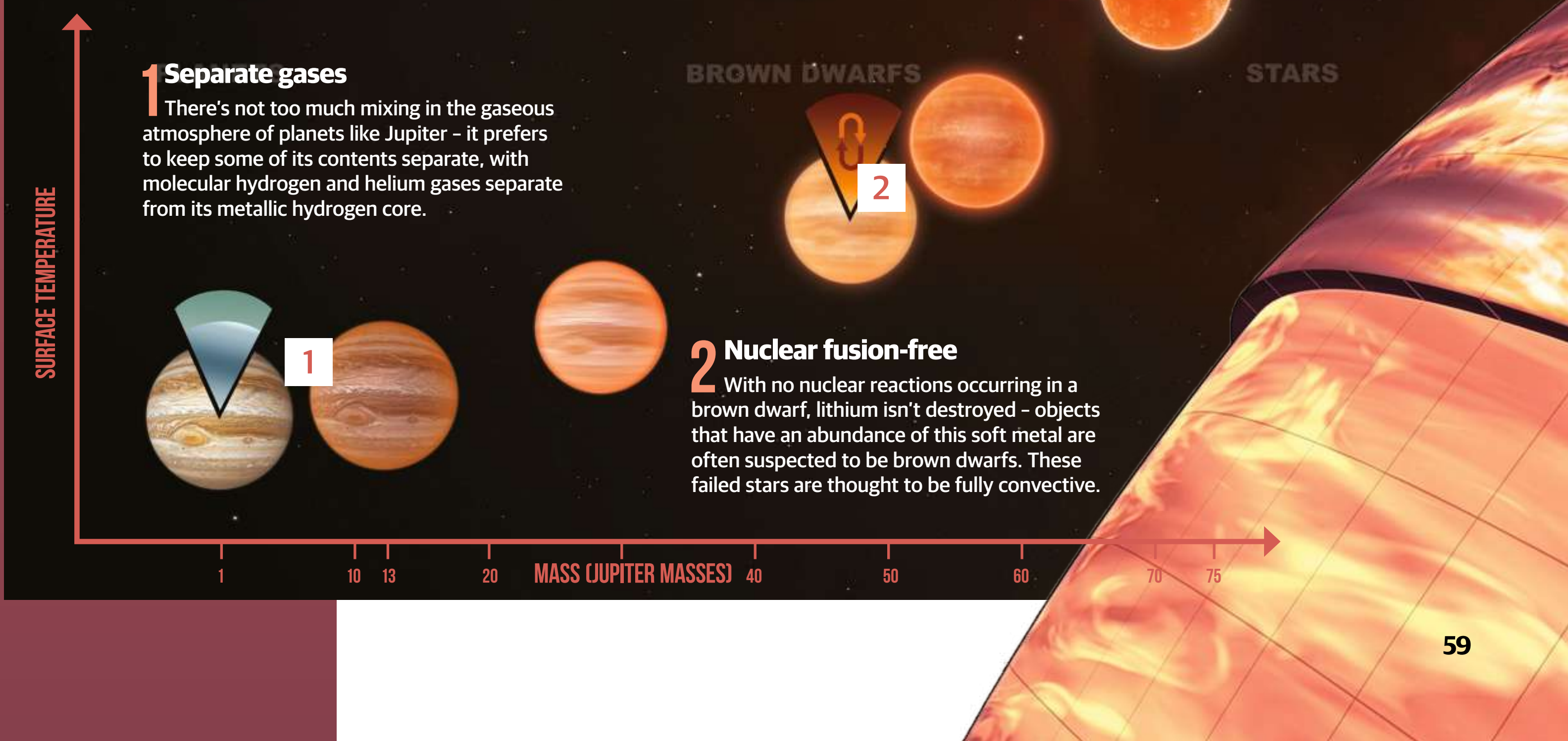
Astronomers then had to wait nearly another ten years before finding more brown dwarfs, with Teide 1 in the Pleiades star cluster being discovered in 1995. Brown dwarfs had been theorised to exist long before the 1980s, and it was actually Jill Tarter of SETI fame who came up with the name 'brown dwarf' in 1975. Previously they had been known as black dwarfs, but this caused confusion with the other black dwarfs, which are what white dwarfs will eventually become when they cool down over trillions of years. Besides that, in actual fact brown dwarfs are not black, or even really brown - they are more of a magenta shade.

Huge advances in our understanding of brown dwarfs have been made in recent years, mainly thanks to NASA's Wide-field Infrared Survey Explorer (WISE) satellite. WISE spent a whole year scanning the sky in mid-infrared light, wavelengths in which cool brown dwarfs should just pop into view. "The brown dwarfs jump out at you like big, fat, green emeralds," says WISE deputy project scientist Amy Mainzer. They appear green in WISE's images because their temperatures are coded to false colours.

WISE proved to be a prolific brown dwarf discoverer, and it ended up finding the coolest brown dwarfs discovered so far. They are so cool, in fact, that astronomers had to come up with a whole new classification for them.

SEPARATING THE PLANETS FROM THE STARS

MORE MASSIVE AND HOTTER THAN MOST PLANETS, BUT LIGHTER AND COOLER THAN STARS



1 Separate gases
There's not too much mixing in the gaseous atmosphere of planets like Jupiter – it prefers to keep some of its contents separate, with molecular hydrogen and helium gases separate from its metallic hydrogen core.

2 Nuclear fusion-free
With no nuclear reactions occurring in a brown dwarf, lithium isn't destroyed – objects that have an abundance of this soft metal are often suspected to be brown dwarfs. These failed stars are thought to be fully convective.

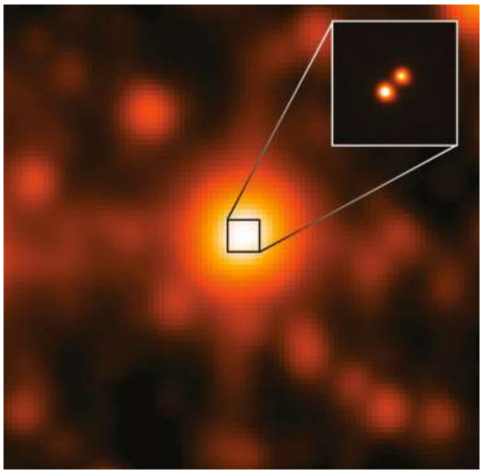
3 The industrious star
The heat and light-generating nuclear reactions in a star's core convert hydrogen into helium. Due to the exotic conditions, lithium isn't able to survive in stars such as red dwarfs.

© NASA

Stars are grouped into types dependent on their temperature and luminosity. The hottest, most luminous stars are termed O-types. Next are B-types, then A-types, then F-types, G-types - like the Sun - K-types and M-types, the latter of which are red dwarfs. But brown dwarfs are even cooler than red dwarfs, so new types were needed to describe them, namely L and T-types. In 2014, however, astronomers using WISE found a brown dwarf, called W0855-0714, which was so cold that it had a temperature of between -48 and -13 degrees Celsius (-54.4 and 8.6 degrees Fahrenheit). This brown dwarf was described as a Y-type, and only a few dozen more have subsequently been identified. Scientists have not even been able to rule out the possibility of one or more brown dwarfs lying closer to the Sun than the current nearest star, Proxima Centauri, which is 4.2 light years away.

Brown dwarfs are described as being between 13 and 80 times the mass of Jupiter, but W0855-0714 comes in below that, weighing only as much as between three and ten Jupiters, showing how difficult it is to define what a brown dwarf is, at least based on its mass. It has been speculated that it could be an escaped planet, but astronomers suspect it is more likely to be a brown dwarf, simply because there should be so many brown dwarfs that the odds are against it being a rogue planet.

Brown dwarfs may form like stars, but they look more like planets, to the extent that they even have weather and clouds. For example, one brown dwarf, called ULAS J222711, appeared redder than other normal brown dwarfs. Under further inspection, astronomers from the University of Hertfordshire found that it was clouds scattering sunlight that were giving ULAS J222711 its red hue - but these were certainly not clouds like the fluffy water-vapour versions we have in Earth's sky.



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Above: At a distance of 6.5 light years away, Luhman 16 is the closest brown dwarf binary to Earth

"The thick clouds on this particular brown dwarf are mostly made of mineral dust, like enstatite and corundum," says the University of Hertfordshire's Federico Marocco. "Not only have we been able to infer their presence, but we have also estimated the size of the dust grains in the clouds." These dust grains were calculated to be about 0.5 micrometres (0.5 millionths of a metre or 20 millionths of an inch) across. On the brown dwarf W0855-0714 there is also evidence of frozen clouds of sulphides and water-ice, while gases such as methane, hydrogen sulphide and ammonia are taken as a given. "If you could bottle up a gallon of a brown dwarf's atmosphere and bring it back to Earth, smelling it wouldn't kill you, but it would stink pretty bad, like rotten eggs with a hint of ammonia," Mainzer explains.

Most brown dwarfs could also be stormy, further cementing their similarities with Jupiter-like worlds. WISE's infrared predecessor, the Spitzer Space Telescope, has found signs of patchiness in the cloud cover of brown dwarfs, which could equate to roiling storm regions that sport terribly strong winds, enormous lightning strikes and rainfalls - not of water, but of molten sand and iron. "What we see here is evidence for massive, organised cloud systems, perhaps akin to giant versions of the Great Red Spot on Jupiter," said Professor Adam Showman of the University of Arizona.

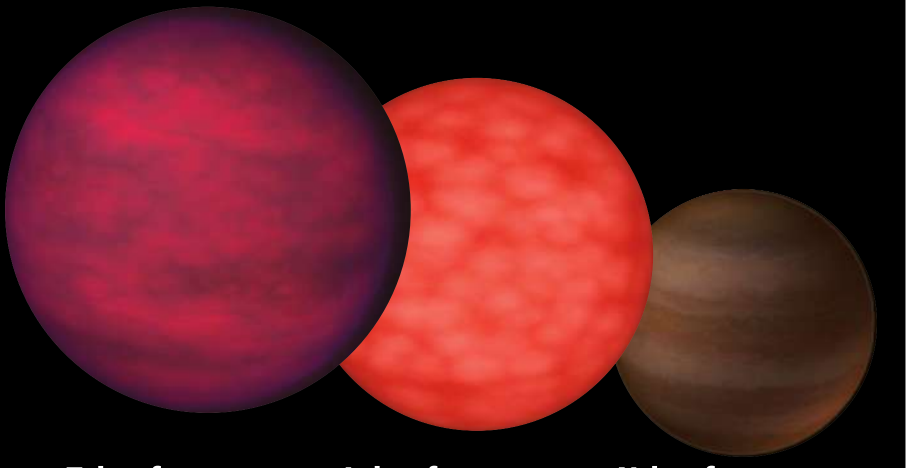
By teaming up Spitzer with Hubble, astronomers were able to look at brown dwarfs in different wavelengths of infrared light, which are able to peer down into different layers of a brown dwarf's atmosphere. As the brown dwarf rotates, variations in the amount of cloud cover and the size of the storms affects the brightness that the Hubble and Spitzer space telescopes can see. "These out-of-sync light variations provide a fingerprint of how a brown dwarf's weather systems stack up vertically. The data suggests that regions on a brown dwarf where the weather is cloudy and rich in silicate vapour deep in the atmosphere coincide with balmier, drier conditions at higher altitudes, and vice versa," explained Showman.

But where do brown dwarfs get the energy from to drive weather and planet-sized storms? On Earth the energy for our weather systems comes from heat emitted by the Sun. Some brown dwarfs are found orbiting stars, but that doesn't explain where brown dwarfs without stellar companions get their heat from. A world like Jupiter, which is far from the Sun, still retains some residual heat within its core from the days when it was formed, and some of the heat of brown dwarfs will come from the same source. However, brown dwarfs have an advantage over worlds like Jupiter.

Although they are lacking too much mass to ever have the required pressures and temperatures in their cores to instigate nuclear fusion of hydrogen into helium, they can for a short while ignite nuclear fusion reactions of deuterium. The most massive brown dwarfs are also able to fuse lithium. Lithium does not exist in any significant quantities in normal stars either, so a search for lithium is a good test of whether an object is a brown dwarf or not. The smallest brown dwarfs, which are less

TYPES OF BROWN DWARF

The different classes and colours of these cool stars



T dwarf

Temperature: 427 to 1,026°C (801 to 1,879°F)
Colour: Dark magenta
Number found: Over 600
Contain: Water, methane and ammonia gases

L dwarf

Temperature: 1,027 to 1,727°C (1,880 to 3,141°F)
Colour: Orange-red
Number found: Over 1,700
Contain: Clouds of 'hot dirt' and other condensates

Y dwarf

Temperature: Less than 327°C (620°F)
Colour: Brown
Number found: Approximately 30
Contain: Possibly water

Right: An infrared image of the Pleiades, or 'Seven Sisters', by the Spitzer Space Telescope

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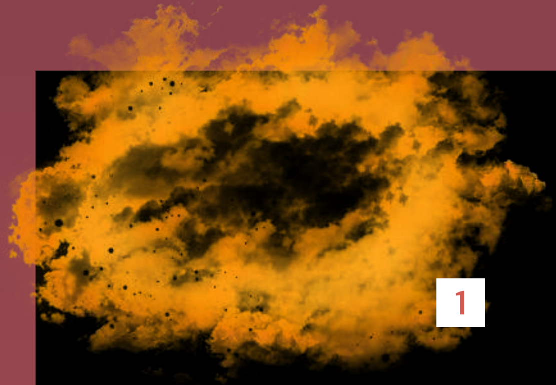
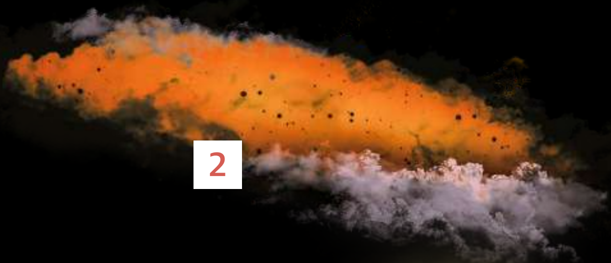
THE MAKING OF AN EPIC FAIL

What happens when collapsing clouds of gas and dust don't make it as stars



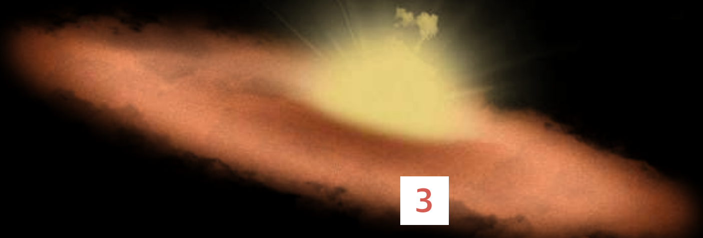
1 The stellar nursery

Just like main sequence stars like our Sun, these objects come from the collapse of a cloud of gas and dust under its increasing gravity.



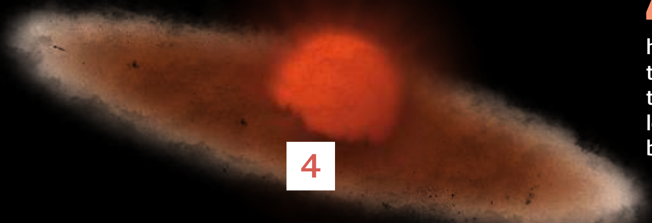
2 The young star

When a cloud of gas and dust caves in, gravity begins to pile up the material tightly to make a very young star – known as a protostar – at its centre.



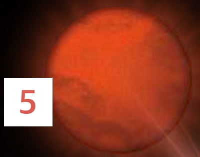
3 Failure to fuse

In a main sequence star, gravity pushes so strongly inward that hydrogen fusion is kick-started in the core. The brown dwarf never reaches this stage, and before the temperatures get hot enough for hydrogen fusion to start, the brown dwarf reaches a stable state.



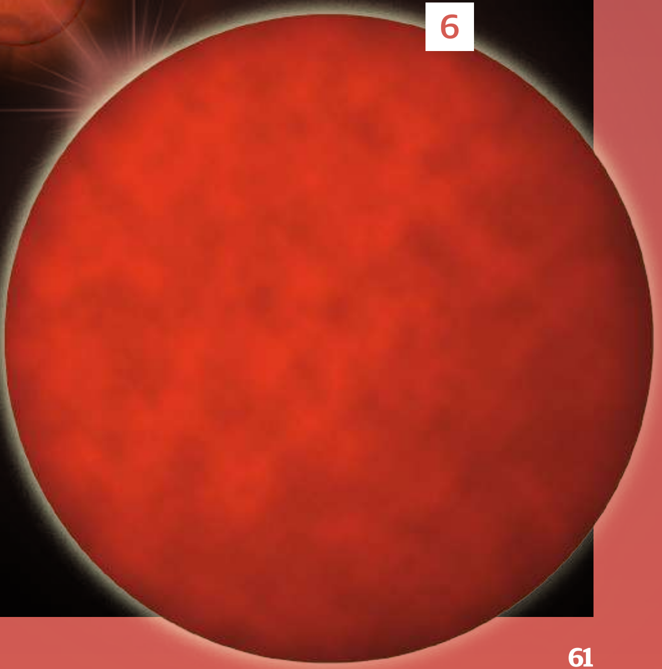
4 The cool brown dwarf

Since they are not very visible to the human eye, telescopes need to observe them in infrared wavelengths to pick up their heat, which is considered to be very low compared to their blazingly hot and bright stellar cousins.



5 Brown dwarf types

Just like stars, which are categorised by a spectral class, brown dwarfs sit in the classes L, T and Y. The coolest is the rare Y dwarf, which can be colder than the human body. Some – but not all – hotter M-class stars can also be brown dwarfs.



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6 Colours and flavours

Belonging to different classes means that brown dwarfs contain different gases and appear in differing colours. A T dwarf appears as a dark magenta and contains a gaseous mixture of methane, water and ammonia, while Y dwarfs take on a browner shade and are likely to contain a good amount of water.

BROWN DWARF DISCOVERY

NASA's WISE telescope is an expert when it comes to hunting down brown dwarfs

2011

The spacecraft confirms the existence of a new class of brown dwarf, known as the Y dwarf. These brown dwarfs can have temperatures as cool as the human body.

2013

The discovery of the closest brown dwarfs to Earth is announced. They were discovered using WISE at a distance of 6.5 light years away, and are locked in a binary system called Luhman 16.

2014

WISE discovers the coldest known brown dwarf so far, which has an ultra-cool temperature between -48 and -13 degrees Celsius (-54.4 and 8.6 degrees Fahrenheit).

2020

With the help of citizen scientists, two of the most planet-like brown dwarfs are discovered in the Milky Way's oldest population of stars.

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Above: The first brown dwarf to be verified, known as Teide 1, rests in the famous Pleiades star cluster

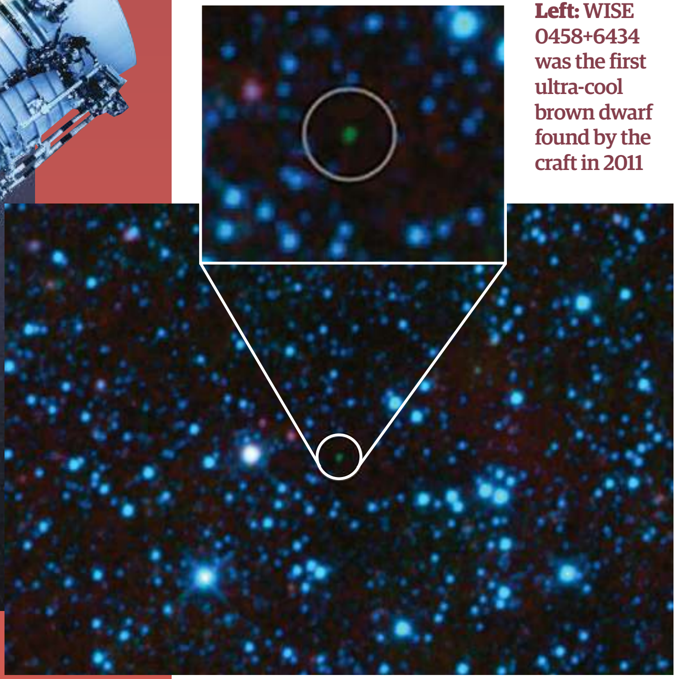
than 13 times the mass of Jupiter, are nowhere near hot enough in their cores for any fusion reactions. Nevertheless, those that are able to start the reactions can, for a short while, produce heat and energy this way, which resides in the star for billions of years after the fusion reactions have actually run themselves out.

Inside a star like the Sun, there are two zones. The innermost is the radiative layer around the nuclear core, where energy produced by fusion reactions is transported through radiation. It is this energy that holds the Sun up against the pull of its gravity. Above the radiative layer is the convective layer, where convection currents transport the energy the rest of the way to the Sun's surface. Brown dwarfs, however, are suspected to only have convective layers. This leads to their interiors being 'springy', so they can become more compressed with greater mass. This results in brown dwarfs that are not much larger than the diameter of Jupiter despite some having dozens of times more mass.

This could result in the surprising scenario where a planet orbiting a brown dwarf is actually bigger than the brown dwarf itself. Given brown dwarfs are not proper stars, it had been uncertain as to whether planets could form around them. However, the Atacama Large Millimeter/submillimeter Array (ALMA) in the Chilean desert has discovered a disc of dust and rubble around a brown dwarf, just like the planet-forming dust discs that astronomers find around young stars. The disc around the brown dwarf, which is known as ISO-Oph 102 and has 60 times the mass of Jupiter, contains millimetre-sized dust grains. In the planet-forming discs around young stars, these grains gradually begin to stick together, growing larger and larger until they build up into rocky planets.

"We were surprised to find millimetre-sized grains in this thin little disc," says Luca Ricci of California State University Northridge, who headed the team of astronomers that used ALMA to find this disc. "Solid grains of that size shouldn't be able to form in the cold outer regions of a disc around a brown dwarf, but it appears that they do. We can't be sure if a whole rocky planet could develop there, or already has, but we're seeing the first steps."

This leaves brown dwarfs facing something of an identity crisis. They form in the same way that stars do but are not stars, unable to fuse hydrogen into helium. They look like planets with weather systems, but are more massive and do not form like planets, yet they may be able to form planets orbiting around them. They are likely the most common type of object in the universe - some scientists even suspect there could be enough brown dwarfs to account for some of the missing mass that has been attributed to dark matter. Yet despite all of this they will always be seen as failures, objects that couldn't become stars, when really we should see them as super-planets that take on some star-like qualities. The brown dwarf is truly a unique breed of object, capable of taking on the role of both planet and star, while possibly revealing more about our hidden universe.



Left: WISE 0458+6434 was the first ultra-cool brown dwarf found by the craft in 2011

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MYSTERIES OF THE UNIVERSE

THE STRANGE YELLOW SKIES OF WASP-79B

Astronomers will feel blue if they don't discover why this hot-Jupiter exoplanet has an odd-coloured sky

Reported by David Crookes

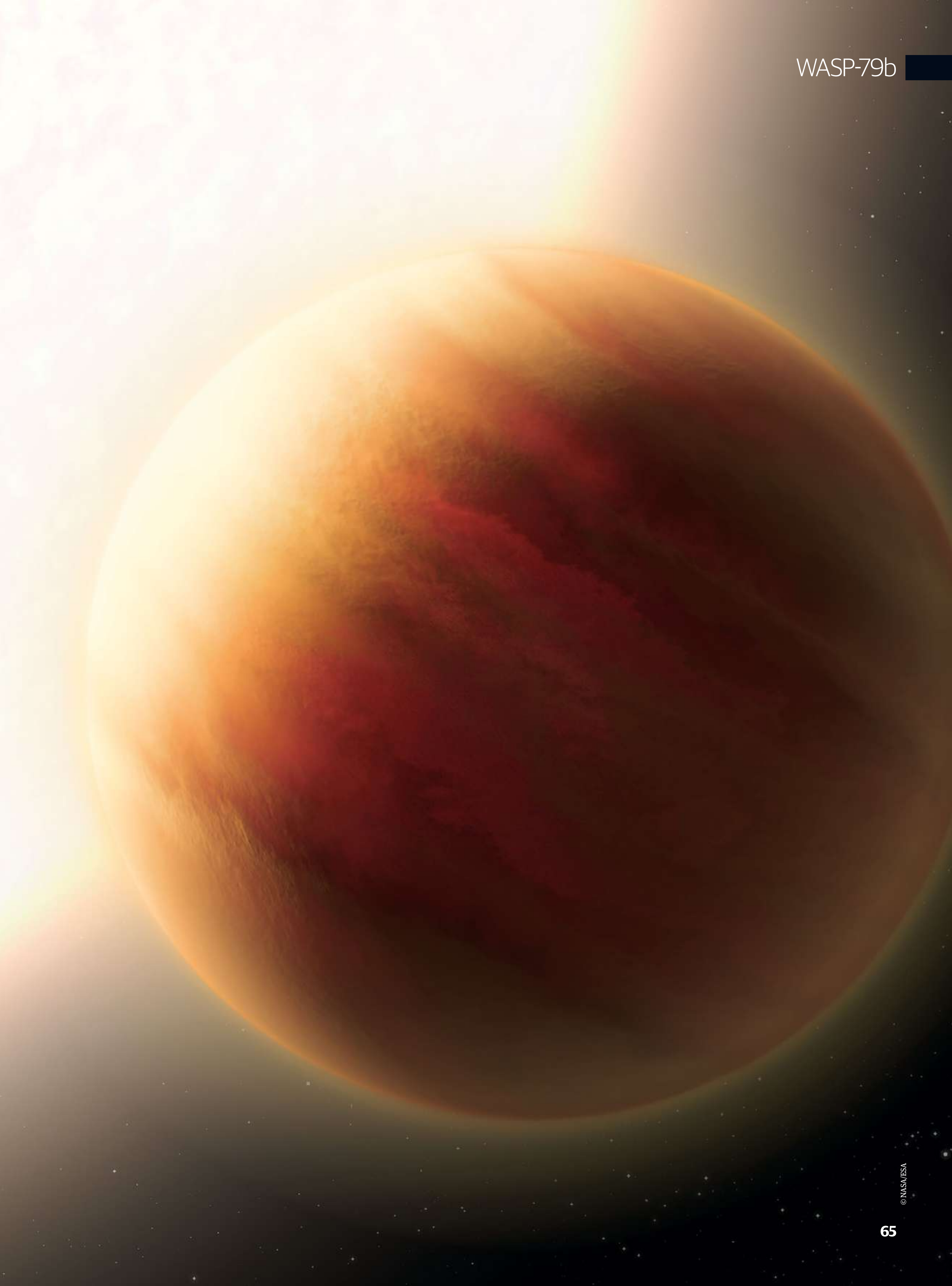
If you're looking for an ideal holiday destination, one thing's for sure: you are not going to be choosing WASP-79b. As curious as this huge, hot exoplanet has proven to be ever since its discovery by Dr Barry Smalley of Keele University, UK, in 2012, anyone deciding to lay on their deckchair and look skywards is going to be in for something of a surprise.

Here on Earth the sky is a glorious blue, and that's because the white light from the Sun - which is made up of all the colours of the rainbow - enters the atmosphere, bounces off small particles and causes the shorter blue and violet wavelengths to become separated from the longer red, yellow and green. As the violet light is mainly absorbed by the upper atmosphere, it leaves the blue waves to be dispersed.

"This is called Rayleigh scattering, and it's the primary effect that makes Earth's sky look blue," says Kristin Showalter Sotzen of the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. "If WASP-79b had Rayleigh scattering, its sky would also have more of these shorter, bluer wavelengths, and so it would appear to have a blue or blue-green hue, depending on what the particles are actually made of." And yet it doesn't. Instead observations suggest that WASP-79b has a total absence of this effect, which means the blue light is able to join the others in making its way through the atmosphere without any obstruction.

That has led scientists to believe that the sky is a very different colour to the one that we've become accustomed to. "You would expect to observe more yellow tones in the atmosphere," adds Sotzen. In other words, this exoplanet's daytime skies are likely tinged yellow - something which goes against physical models - and now astronomers are keen to discover why.

Over the past eight years, scientists have been building up a reasonable bank of knowledge about WASP-79b, an exoplanet which lies in the constellation Eridanus some 810 light years from Earth. It is known, for instance, that the celestial



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WASP-79B BY NUMBERS

810
light years away

1,650
Temperature of its atmosphere in degrees Celsius

83.3°
The planet's orbital inclination

0.85
Its mass in comparison to Jupiter

116,751
Radius in kilometres

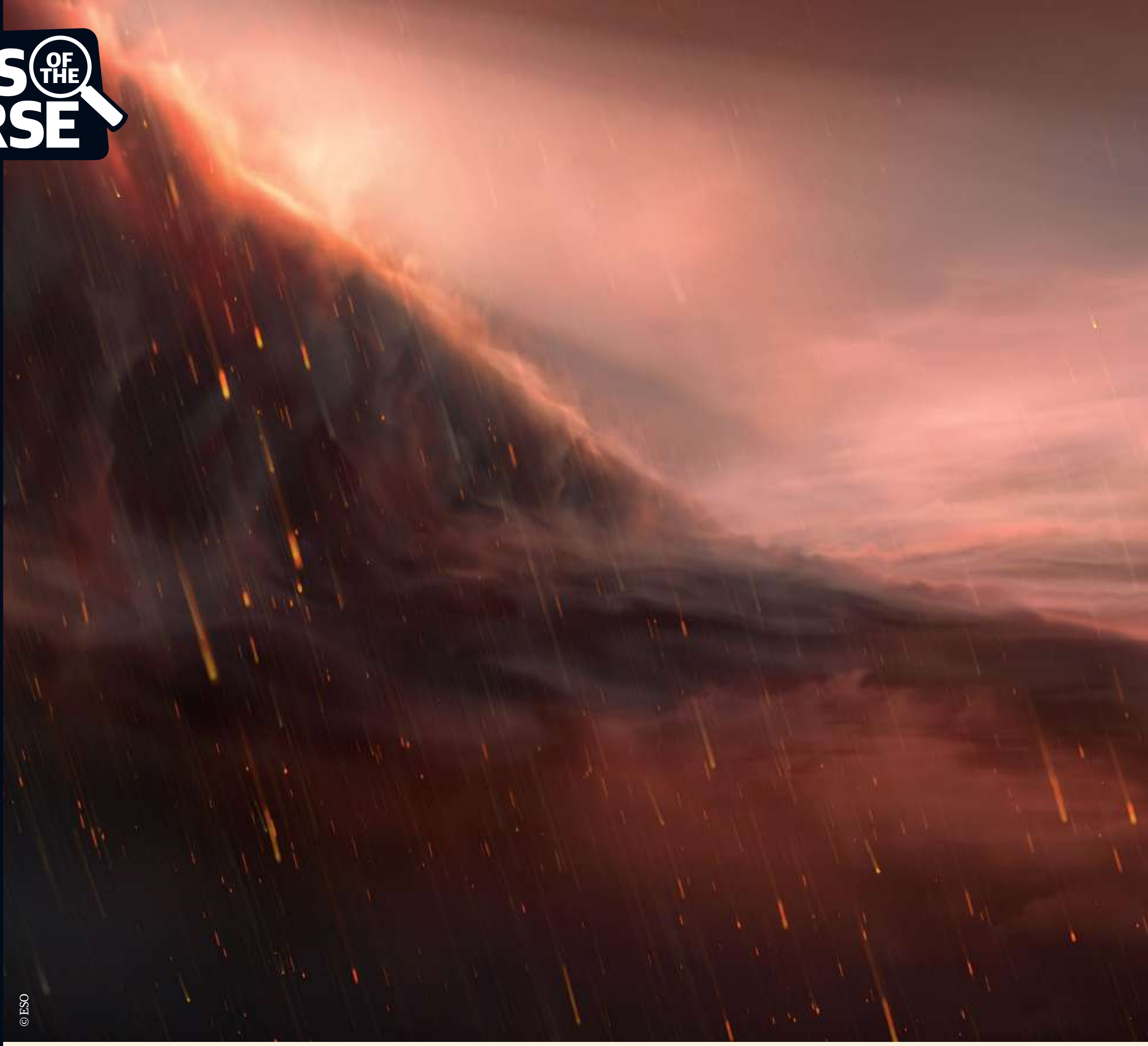
1.67x
the radius of Jupiter

3.7
The number of days it takes to orbit its star

2012
The year it was discovered

0.0
WASP-79b's eccentricity

0.0519
Its orbital radius in astronomical units



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Above: Iron rain is believed to fall on the ultra-hot giant exoplanet WASP-76b, with scientists believing the same occurs on WASP-79b

body – also referred to as Pollera after the traditional costume worn by Panamanian women in the elegant El Punto dance – closely orbits its star, WASP-79, at roughly one-eighth the distance that Mercury orbits our Sun.

What's more, it's been observed to be a steaming ball of gas – a body that scientists refer to as a hot Jupiter – with a terribly humid atmosphere and a seriously sweaty heat of 1,650 degrees Celsius (3,000 degrees Fahrenheit), making it even less ideal for a vacation.

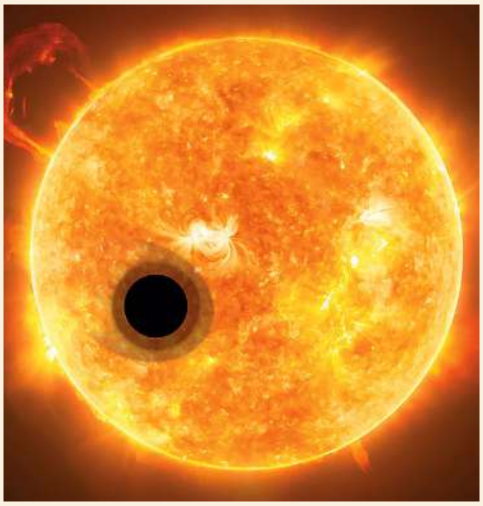
That's in most part due to the star being 1.64 times the radius of the Sun. WASP-79 is also of spectral type F3, which makes it far hotter than the Sun, which incidentally is classified as G2, with the scale running O, B, A, F, G, K and M – with O being the hottest and M the coolest.

"WASP-79b orbits its star in about 3.5 days, so it's very hot – even hotter than Venus and Mercury," says Sotzen of an exoplanet that's 1.67 times the radius of Jupiter, although only 0.85 times the mass. "Since it's a gas giant like Jupiter, we wouldn't expect it to have a surface, so there wouldn't be anywhere to stand. However, it does have a substantial atmosphere, so the best way to visit would probably be to fly through the atmosphere. If you could fly around WASP-79b, it would probably be similar to flying through Venus' atmosphere – hot with a lot of haze and clouds."

> "IF WASP-79B HAD RAYLEIGH SCATTERING, ITS SKY WOULD ALSO HAVE MORE OF THESE BLUER WAVELENGTHS"
>
> KRISTIN SHOWALTER SOTZEN

We're unlikely to travel to WASP-79b, but that doesn't mean astronomers can't continue to get a closer look and work out what's happening from afar. As one of the largest known exoplanets, WASP-79b is certainly a compelling alien world, and it's been a major focus for space agencies and university researchers for the best part of a decade.

As with so many, Sotzen is interested in discovering more about WASP-79b, as well as the atmospheres of other exoplanets, so she led a study which looked at data collected from the Wide Field Camera 3 on the Hubble Space Telescope, the Transiting Exoplanet Survey Satellite (TESS) and the Baade and Clay telescopes built by the Carnegie Institution of Washington at Las Campanas



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Left: The Wide Angle Search for Planets (WASP) looks to find exoplanets using the transit method

Below: The Magellan Telescopes were used to observe WASP-79b along with Hubble and Spitzer

Source: Wikipedia Commons © Jan Skowron

Observatory in Chile, known collectively as the Magellan Telescopes. In particular, Sotzen and the other team members have used the Low-Dispersion Survey Spectrograph-3 (LDSS-3) instrument that's fitted to the Clay telescope. It splits light into its component wavelengths and allows research teams to analyse chemical compositions.

So what has been found? Far from discovering that WASP-79b had a decrease in blue starlight, which would have been expected had Rayleigh scattering occurred, Sotzen and her team found very little evidence of absorption and scattering. "We have not yet observed a spectrum like this for other exoplanets, and we typically see evidence for Rayleigh scattering in the atmospheres of hot Jupiters," says Sotzen. "Having more good-quality optical data for hot Jupiters would give us a better idea of how unusual WASP-79b really is, though, and since Rayleigh scattering is caused by small particles in the atmosphere, the spectrum for WASP-79b is likely the result of the atmosphere being dominated by large particles more consistent with haze or smog."

As such, scientists are now hoping to discover more about the composition of the atmosphere to work out what large particles are at play. Thankfully, more data may be forthcoming in the near future, and if things go to plan then this may help astronomers work out if unknown atmospheric processes are in play.

HOW DOES RAYLEIGH SCATTERING WORK?

The composition of a planet's atmosphere and the colours of light transmitted are related

1 Scattering of blue light

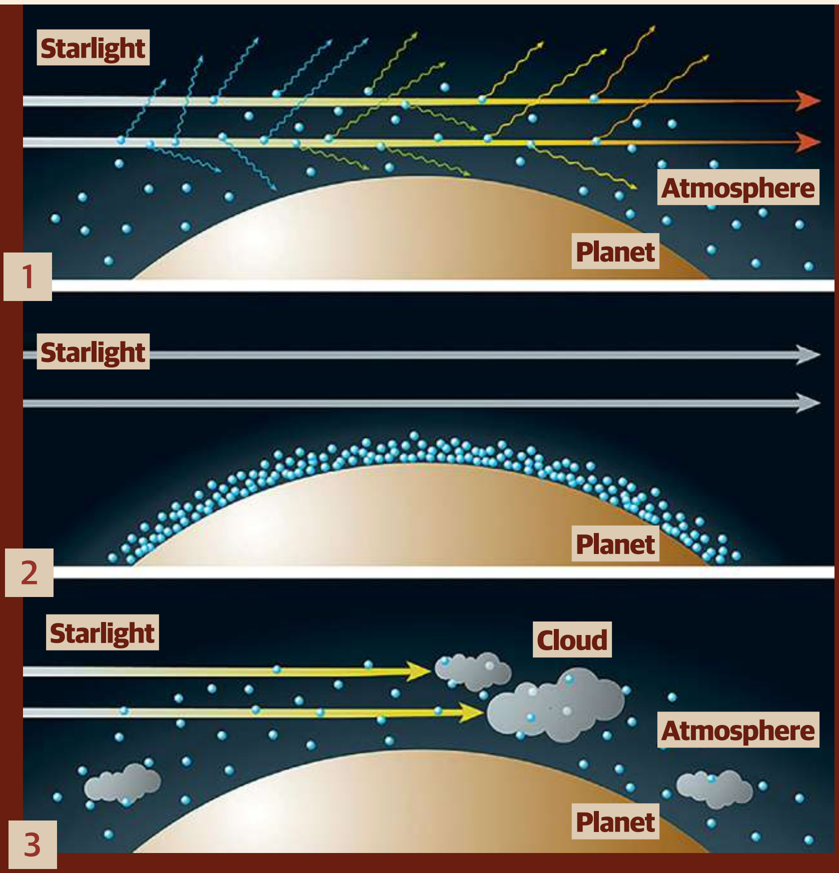
When light from a star reaches a planet's hydrogen-dominated atmosphere, it will interact with particles present in the air. Tiny gas molecules will scatter the starlight's shorter blue wavelengths, giving the sky its colour, while longer wavelengths pass straight through the atmosphere.

2 Allowing visible light to pass

If an atmosphere is less extended – and rich with water rather than hydrogen – then the starlight will not interact with any particles and it will pass through.

3 Travelling through clouds

A cloudy, hydrogen-dominated sky will equally prevent all of the visible light wavelengths from being transmitted through the atmosphere, and so the colours will have roughly the same transit depths.



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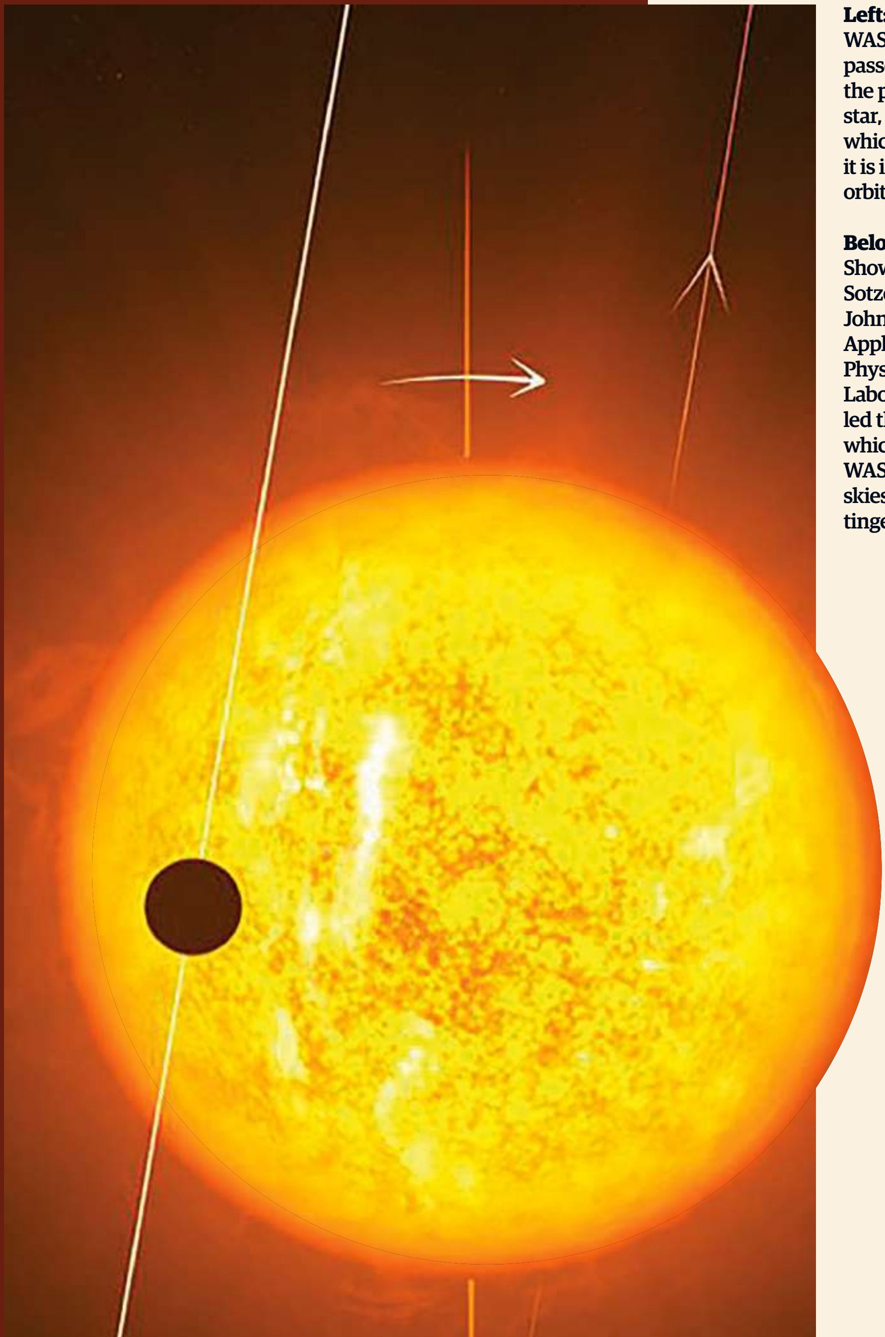

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Left: WASP-79b passes over the poles of its star, WASP-79, which means it is in a polar orbit of its host

Below: Kristin Showalter Sotzen from Johns Hopkins Applied Physics Laboratory led the study which suggests WASP-79b's skies are tinged yellow

For starters, in November 2019 WASP-79b was chosen as an Early Release Science target for the James Webb Space Telescope - the planned successor for Hubble - although it's since become a back-up target, disappointingly in terms of this mystery. If it does end up being observed by Webb, however, then the improved infrared resolution and sensitivity of the telescope means there's a chance more information will be imparted about why WASP-79b's skies are yellow.

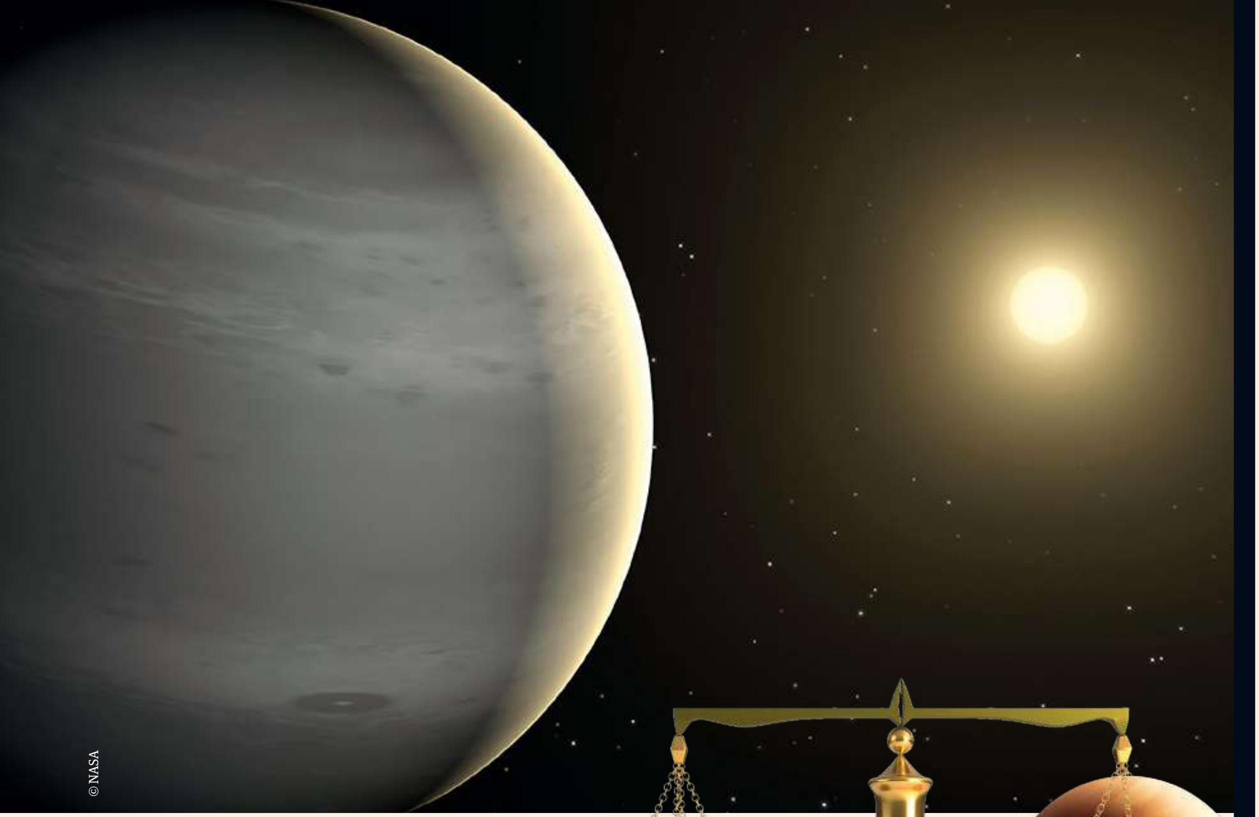
Astronomers are in agreement that WASP-79b is a fascinating planet, not least because it has shown signs of water vapour in its atmosphere - an intriguing discovery which prompted astronomers to pick the exoplanet for the Early Release Science program in the first place.

Data has also shown that the atmosphere of WASP-79b has signs of scattered manganese sulphide or silicate clouds, which is typical of hot Jupiters. It may rain molten iron, thereby making it even less of a holiday destination than you could ever imagine - not that anyone would be expecting WASP-79b to show any evidence of life in its sky, since the exoplanet's position and intense heat would likely prove too hostile.

"Very hot planets like WASP-79b can have temperatures high enough to vaporise metals like iron and manganese and loft them into the atmosphere," explains Sotzen. "Temperatures near the top of the atmosphere are cooler, so when these materials are transported high into the atmosphere, they can cool and condense and potentially 'rain' back down, similar to the process we see in Earth's water cycle. Via this process, it is possible for very hot planets to have metal 'rain', though it might not be rain in the way we think of it for Earth!"

Researchers are hoping that WASP-79b is not a one-off, and they will continue to analyse not only this exoplanet, but other hot Jupiters in the hope of finding more clues about its atmospheric evolution. Without further discoveries, it's going to be much more difficult to ascertain whether or not the yellow skies are being caused by an atmospheric phenomenon linked to the evolution of the planet. Only by finding similar exoplanets can this mystery be truly resolved.

And yet this isn't looking like it's set to be an impossible task, since one of the benefits of targeting these celestial bodies as opposed to others is that they're actually easier to detect using transits and radial velocity. WASP-79b also has the added benefit of an extended atmosphere, which makes it easier to analyse starlight, which ends up grazing and filtering through the atmosphere as it heads towards our planet. Looking at the transit at different wavelengths allows scientists to examine the atmosphere and discover more about the composition, size and orbits.



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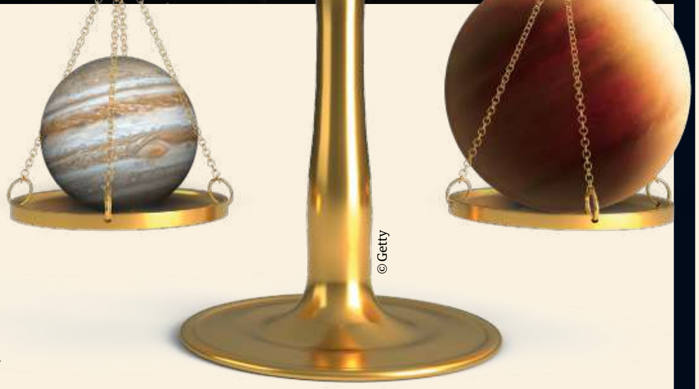

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What is seen in one atmosphere provides clues and a greater capacity to make a prediction about the others, enabling scientists to work out what molecules are likely to be present and whether clouds are in the sky. They look out for methane, nitrogen and oxygen, again to find signs of life and figure out whether an exoplanet may be habitable - a haze could point to the presence of liquid water pooling on the surface of an orbiting planet, for instance.

"Our findings are exciting because they're - to our knowledge - unique among hot Jupiter spectra," says Sotzen. "The implication is that WASP-79b may have larger particles in its atmosphere than other observed hot Jupiters, which may have repercussions for atmospheric chemistry models."

WASP-79b is also particularly interesting, according to the team at Johns Hopkins University Applied Physics Laboratory, because its average gravity is roughly the same as that of Earth. This is allowing them to examine potential links between cloudiness, temperature and gravity.

What's more, the planet has a polar orbit, too - which means it passes over its star's poles. Again this is unusual, with some astronomers suggesting that they may be influenced by other yet-to-be-discovered planets that are located further away. In any case, it's not entirely fitting with how planets are thought to form.

"We still have a great deal to learn about the formation and evolution of planets of all types," explains Sotzen. "Our results indicate that the atmospheric chemistry of hot Jupiters may be more complex than previously assumed, so we should continue development of atmospheric chemistry models, especially if we find other exoplanets with similar spectra."

> "WASP-79B ORBITS ITS STAR IN ABOUT 3.5 DAYS, SO IT'S VERY HOT – EVEN HOTTER THAN VENUS AND MERCURY"
>
> KRISTIN SHOWALTER SOTZEN

The more information that astronomers glean from WASP-79b, the more understanding will be gained over how hot Jupiters form. Webb may detect new molecules not yet seen in exoplanet atmospheres, and it would look for abundances of water, carbon monoxide and carbon dioxide. "There is still a lot to learn about planetary atmospheres and how they work, so the exoplanet science community needs to continue development of our atmospheric models," Sotzen adds. "We also need to collect atmospheric spectra of more exoplanets so that we can study trends between different types of planets." This is a mystery that could be well on its way to being solved.

Top: WASP-79b is a gas giant just like Jupiter, and it orbits very close to an F-type star

Above: WASP-79b is larger than Jupiter, but it's much less dense, so it is roughly the same mass

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

THE THEORIES

Why does WASP-79b's atmosphere appear to be yellow rather than blue as it is on Earth?

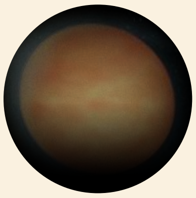
The particles are heavier

The most likely explanation for a lack of Rayleigh scattering – and therefore the yellow light – is that the particles in the atmosphere are larger than those that are normally observed, and so they are absorbing the shorter wavelengths rather than scattering them. Since the transmission spectroscopy only probes the upper regions of the atmosphere, these appear to be high up.

Source: Wikipedia Commons © Public Doamin

There are higher altitude hazes

As such, WASP-79b may also have hazes at a higher-than-expected altitude – again these are made of heavier particles and tend to mute the effects of Rayleigh scattering because the shorter wavelengths get absorbed. Given the transmission spectroscopy only probes the upper regions of the atmosphere, such an effect wouldn't be seen if the haze was lower.



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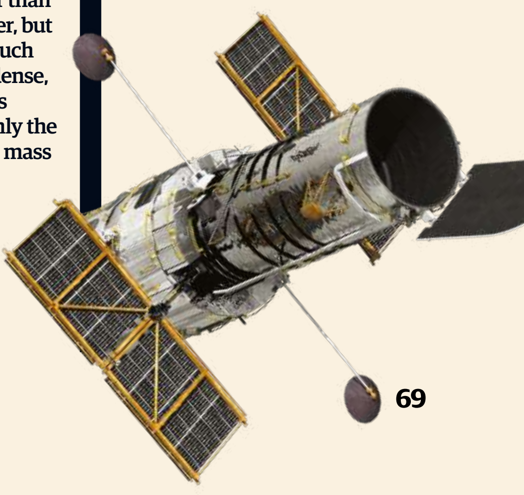
The data became contaminated

Those two theories are actually intertwined, so astronomers are suggesting there are large particles higher in the atmosphere than we would normally see. The only other real explanation for the observed lack of Rayleigh scattering is that the data was noisy, and that there was contamination in WASP-79b's spectrum from Earth's atmosphere that astronomers couldn't correct for.



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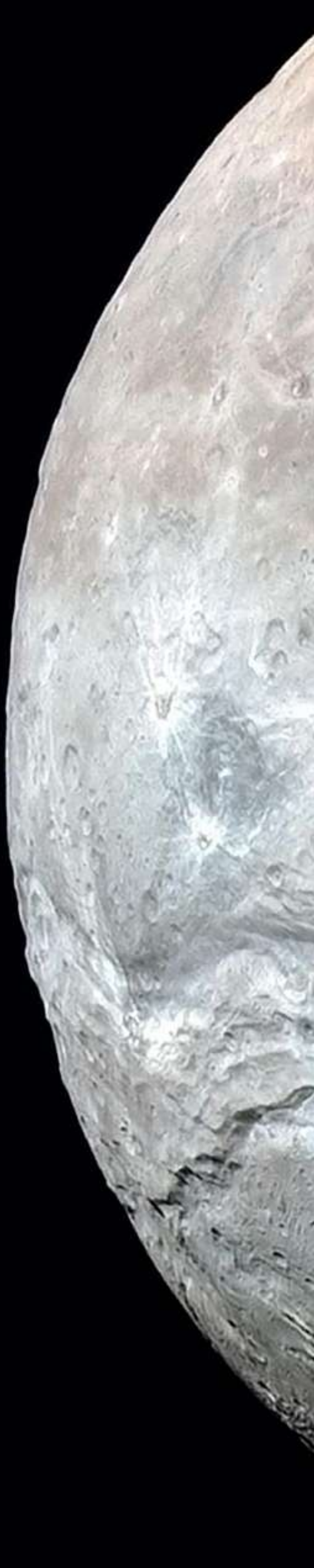
MOON PROFILE

Charon

The secrets of Pluto's largest moon



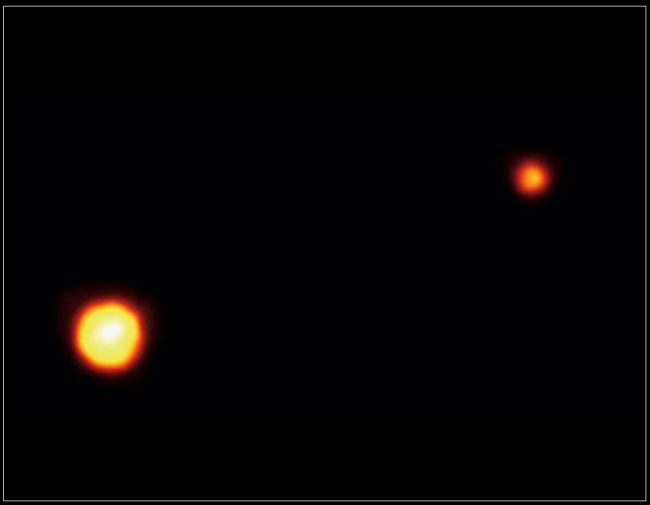
Nobody knew it was there until 1978. For almost 50 years after Pluto's discovery in 1930, the dwarf planet had no known companions out there on the edge of the Solar System. Today, of course, in the wake of the New Horizons mission and a myriad of discoveries since the first inklings of the Kuiper Belt came in 1992, we know it positively teems out there. Charon is one of a system of five moons, and Pluto is the largest member of a huge collection of objects orbiting beyond Neptune. The ongoing hunt for a large planet in the extreme reaches of the Solar System has so far come to nothing, and this is the domain of the small, with Pluto's reclassification as a dwarf planet just the first in a whole raft of triumphantly tiny accolades.

Pluto's largest moon, however, has some remarkable features of its own, despite only having a diameter of 1,212 kilometres (753 miles) – about 10.5 per cent that of Earth's. One-eighth the mass of its co-orbitee Pluto, and half the diameter, it's tidally locked to the larger body, but large enough that the two orbit a centre of mass between them. The International Astronomical Union's general assembly considered a proposal in 2006 to reclassify the pair as a double planet, but despite it being spherical, it wasn't clear Charon was in hydrostatic equilibrium, a state in which the force of gravity is balanced by outward pressure from the body. This state is necessary to give it dwarf planet status.

Charon's name, which it shares with the ferryman who takes souls over the River Styx to Hades in Greek mythology – pronounced with a hard 'K' sound at the beginning – where they're guarded by the three-headed dog Cerberus, comes from its discoverer James Christy, whose wife is named Charlene – he pronounces Charon with a 'sh' sound, as does the New Horizons team. But a 1940 novel by Edmond Hamilton, *Calling Captain Future*, names three Plutonian moons as Charon, Styx and Cerberus. Whatever the origin, the name was officially announced in January 1986, replacing the temporary designation S/1978 P 1. As more moons were discovered around Pluto, they were named Styx; Nix, the Greek goddess of the night; Kerberos – Cerberus was already taken by an asteroid – and Hydra, a nine-headed water monster.

Charon orbits so close to Pluto that when examining photographic plates of the erstwhile planet, taken using the 1.55-metre (61-inch) telescope at United States Naval Observatory Flagstaff Station, all he saw was a bulge in the shape of the tiny disc. By revolving around the disc with time, it revealed itself to be a moon. It wasn't until the development of adaptive optics for Earth-based telescopes that it became possible to resolve the pair as separate discs. The bodies whip around each other once every 6.4 days at an average distance of 19,640 kilometres (12,203 miles), and take 248 years to complete a trip around the Sun.

We had to wait until the New Horizons probe entered the system in 2015 to get a really good look at Charon. A largely grey world of rock and water ice with a reddish cap at its north pole, it remains a fascinating part of the Solar System with more secrets to be discovered.



Below: Charon is half the size of its parent body, dwarf planet Pluto

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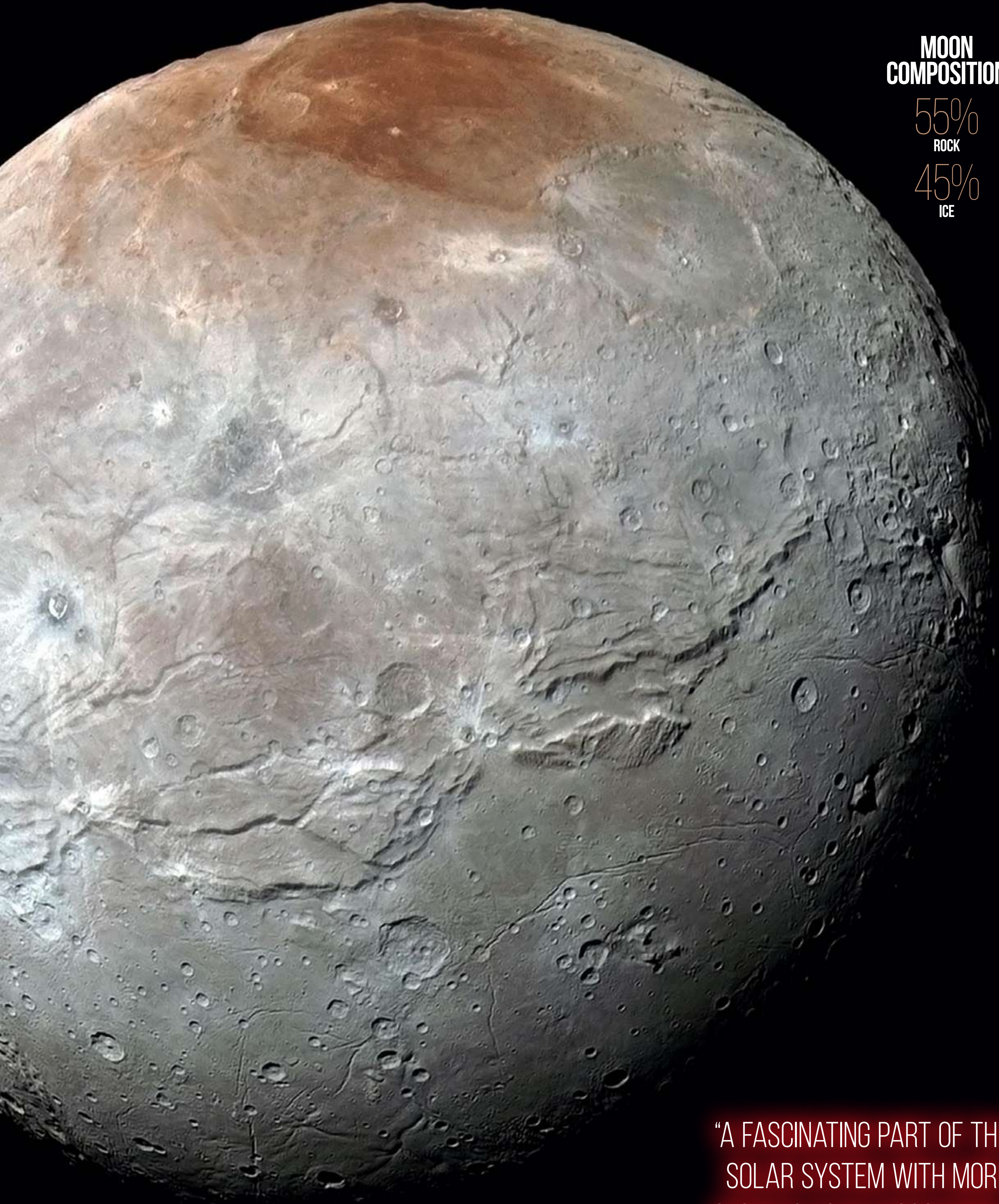

MOON COMPOSITION

55%
ROCK

45%
ICE

> "A FASCINATING PART OF THE SOLAR SYSTEM WITH MORE SECRETS TO BE DISCOVERED"

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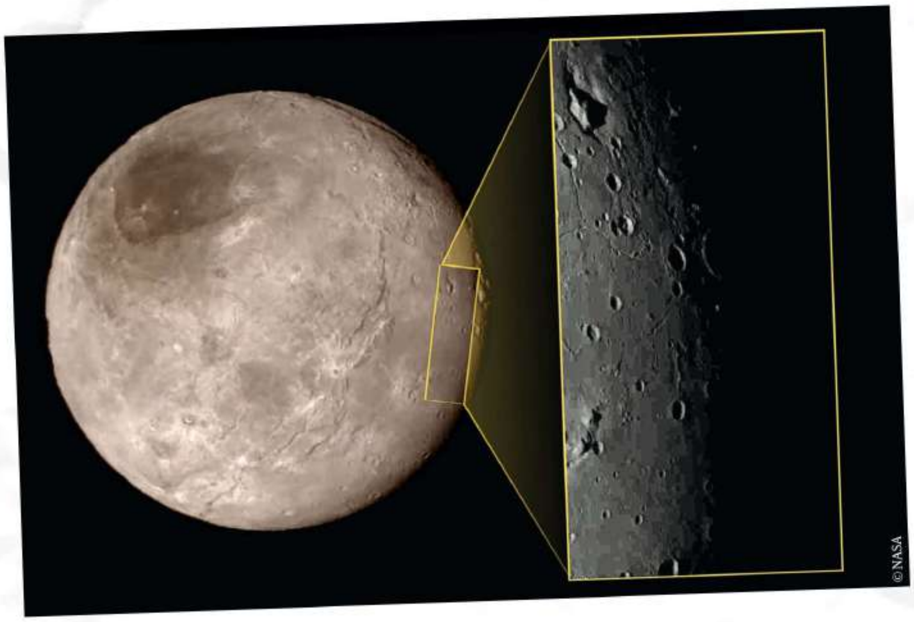
NEWS FROM CHARON

Fantasy features

Various features on the surface of Charon, imaged by the New Horizons probe, have been given official names by the International Astronomical Union Working Group for Planetary System Nomenclature. The names reflect travellers and explorers, especially those with mysterious destinations. Dorothy Crater, for example, is named after the protagonist from *The Wizard of Oz*, while Caleuche Chasma is named for the mythological ghost ship that travels the seas around the small island of Chiloé off the coast of Chile. Mandjet Chasma is named for one of the boats in Egyptian mythology that carried the Sun god Ra across the sky each day, and Nemo Crater honours the captain of the Nautilus, the submarine in Jules Verne's novels *Twenty Thousand Leagues Under the Sea* and *The Mysterious Island*. The New Horizons team had their own names for distinctive areas of the moon, including Oz Terra, Charon's only highland region, named after the land of Oz, and McCaffrey Dorsum, the moon's only ridge, named after science-fiction author Anne McCaffrey.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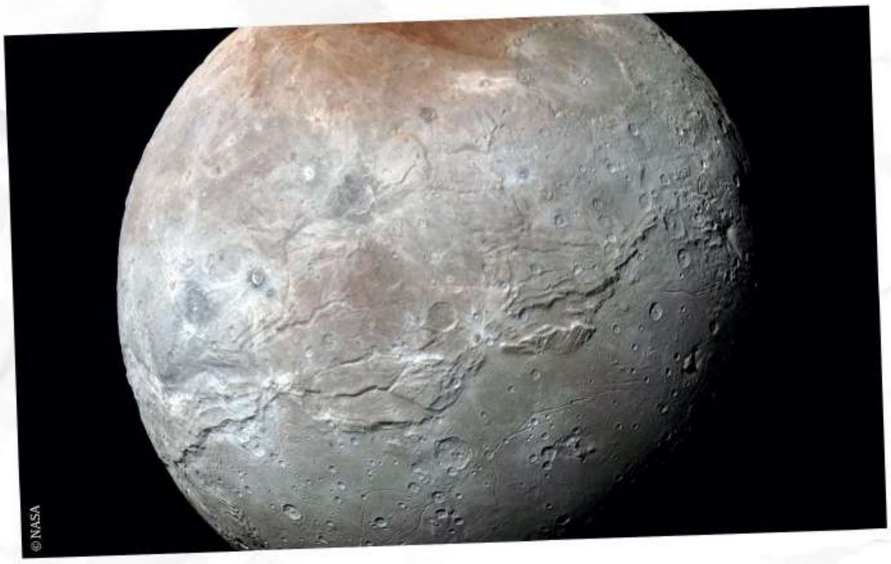
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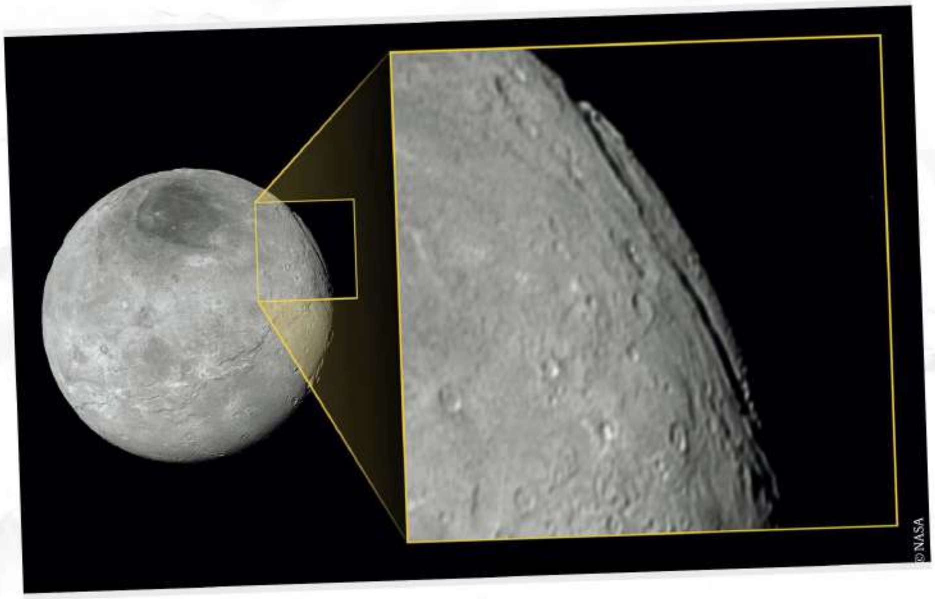
What's in the cap?

Charon's north polar cap is a different colour to the rest of its surface, and there might be a fascinating explanation: Pluto may be sharing its atmosphere with its largest moon. A study from the Lowell Observatory in Arizona modelled conditions on Charon over the past few billion years and discovered that radiation had been stripping the hydrogen from frozen methane on the dwarf planet's surface. This left behind carbon, which joined with other molecules to make heavier materials more able to stick to the surface rather than be lost to space. These became organic molecules called tholins, which produce the red hue. There was speculation after New Horizons revealed Charon's red pole that the cap was enriched with tholins, which could have gotten there via atmosphere transfer. Pluto's gravity isn't high enough to hold onto its thin atmosphere, but Charon's is powerful enough to capture some of the lost gases. Charon's poles freeze the methane, but it evaporates in summer, leaving the heavier, redder molecules behind.

Maps made

The New Horizons spacecraft did more than take photographs when it passed through the system in 2015. The wealth of data it sent back is still being analysed, years after the probe moved on to targets deeper in the Kuiper Belt. New Horizons only directly imaged 45 percent of the surface of Charon in daylight, meaning there are still secrets left to uncover for future missions, but by stitching together images from a pair of New Horizons' cameras, a team from the Universities Space Research Association's Lunar and Planetary Institute in Texas was able to create a height map of the surveyed areas. From this, the size of surface features could be calculated, including the six-kilometre (3.7-mile) high Tenzing Montes, the moon's highest mountains. This height also allows an insight into their composition – methane ice isn't strong enough to support peaks of that height, meaning they must be made of water ice, frozen harder than rock in the chilling temperatures of -250 degrees Celsius (-418 degrees Fahrenheit).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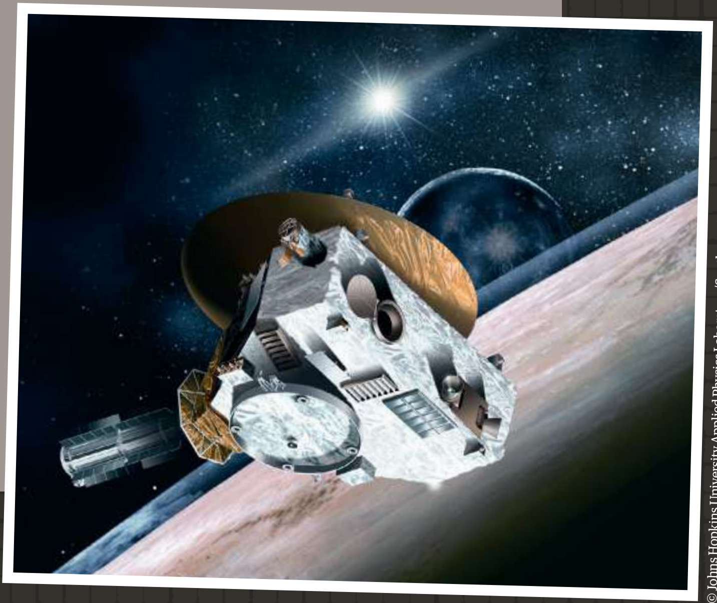
FUTURE EXPLORATION OF CHARON

New Horizons passed through the Pluto system without stopping, and is continuing to speed through the Kuiper Belt on its way out of the Solar System as one of the fastest human-made objects ever launched. Another probe could hypothetically spend much more time investigating Pluto and its moons, using Charon as a source of momentum.

The mission – which is purely theoretical at this point, having been demonstrated by New Horizons' software lead Tiffany Finley – could explore each of the moons in the Pluto system, passing each at least five times, returning to Charon after each one for a course-correcting gravity assist. Using an electric propulsion system similar to that on the Dawn mission to Vesta and Ceres, the tour would only use fuel for 'clean-up manoeuvres' designed to make sure it was going in exactly the right direction, making it an efficient way to visit the moons. The Cassini probe did something similar using Titan while touring the moons of Saturn.

The mission could even be extended so that with one final gravity assist the probe would enter the Kuiper Belt and enter orbit around a second dwarf planet. New Horizons' visit to Pluto was a big success, but it was necessarily limited by the speed at which it passed the system. A second probe spending more time there would perhaps be able to answer many of the remaining questions about Pluto, Charon and its scattering of small moons.



Below: Artist's impression of the New Horizons probe flying by Pluto and Charon

© Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute.

THE EVOLUTION OF CHARON

Date: 4.5 billion years ago
Activity: Two Kuiper Belt objects collide and go into orbit around a shared barycentre.

Date: 1930
Activity: Discovery of Pluto by Clyde Tombaugh.

Date: 1978
Activity: Discovery of Charon by James Christy.

Date: 1980s
Activity: Pluto and Charon eclipse one another several times, allowing astronomers to study their spectra and work out their surface composition.

Date: 1994
Activity: Hubble images Pluto and Charon from 4.4 billion kilometres (2.7 billion miles) away.

Date: 2007
Activity: Observations by the Gemini Observatory suggest there are active cryogeysers on Charon's surface.

Date: 2015
Activity: New Horizons arrives in the system, gathers data and then leaves.

Date: 2017
Activity: NASA's Ames Research Center confirms Charon once had active plate tectonics like Earth.

Date: 2019
Activity: A geomorphological map of Charon's surface is published, dividing the surface into 16 types.

CHARON BY NUMBERS

19,640
KILOMETRES
The average distance between Charon and Pluto

40
KILOMETRES
Diameter of Kubrick Mons, a strange mountain in a moat on Charon

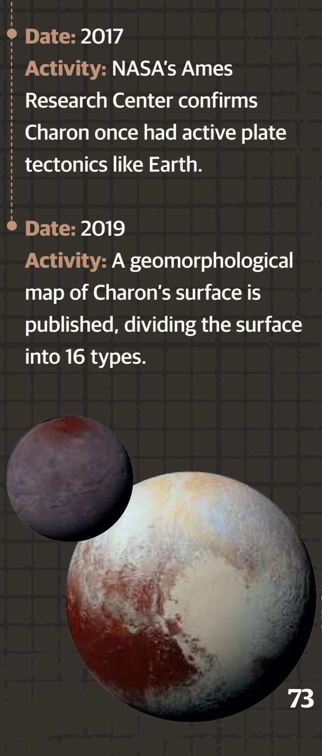
7.5
BILLION KILOMETRES
The distance from Earth to Pluto when they're on opposite sides of the Sun

-258°C
Winter temperature in Charon's north polar region

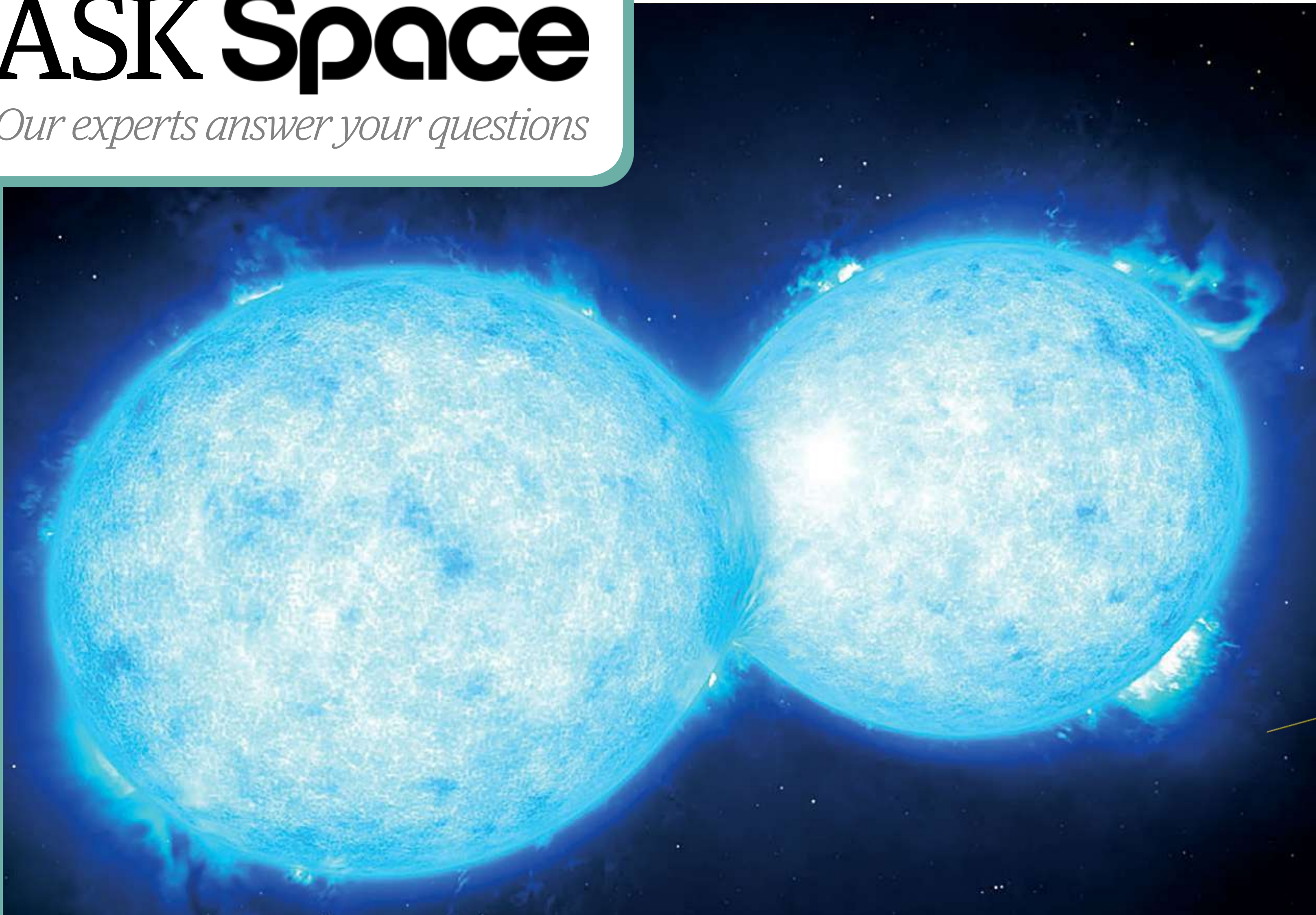
-213°C
Summer temperature in Charon's north polar region

14
KILOMETRES
The depth of Charon's Caleuche Chasma, roughly seven-times deeper than the Grand Canyon

SIX
KILOMETRES
Height of Tenzing Montes, Charon's highest peaks



© NASA



STARS

What would happen if two stars collided?

Collisions between stars are typically very rare because the empty space between stars is huge compared to the size of stars themselves - you could fit 30 million Suns side by side in the distance to our nearest star. However, in the centres of dense star clusters collisions are more probable. Collision results in a more massive star that appears hotter and younger than those of the cluster, and so collisions are the favoured method for creating so-called blue straggler stars.

After the collision, the star will live its life in a fairly typical fashion. In addition to collisions, star 'mergers' are very important in the universe, and happen much more often. A merger is similar to a collision - two stars becoming one - but they arise from pairs of stars that are already orbiting each other in a binary star system.

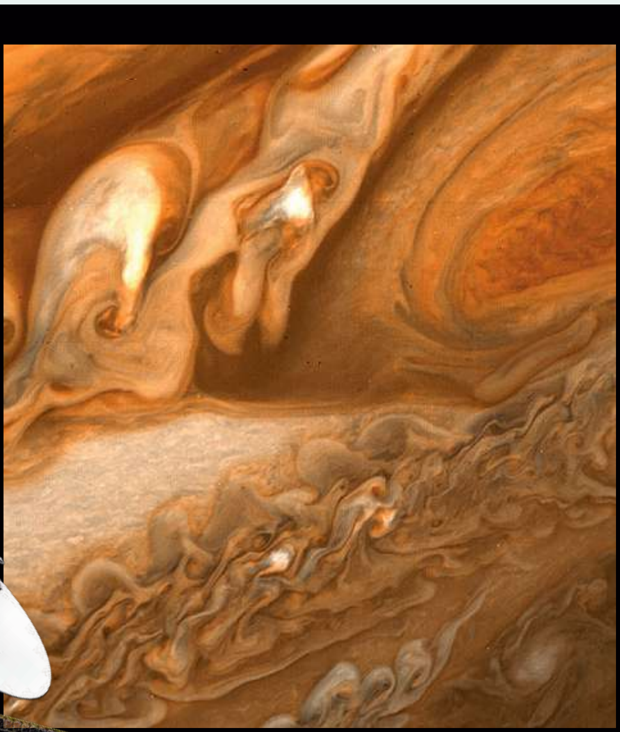
Similar to how the Earth and Sun orbit each other due to their mutual gravitational attraction, we observe many stars that have an orbiting star companion. Over time the orbit can shrink due to various dragging forces and cause the stars to interact in various ways. For example, material may be stripped off one and funnelled onto the surface of another, or one star may swell up and swallow the other star whole.

Things get particularly catastrophic if the stars which are merging are massive, many times more massive than the Sun. In these cases, when the two giant stars merge they produce a single, very massive and rapidly spinning star. We think it is these merged stars that - when they die - give rise to some of the most energetic events in the universe, such as supernovae and gamma-ray bursts.

Dr Joe Lyman is a fellow in the astronomy and astrophysics group at the University of Warwick

Above: An artist's impression of colliding stars in an extreme system about 160,000 light years from Earth

© ESO



© NASA

Right: From north to south – The Great Red Spot, a White Oval, and one of the 13 storms at 41 S, as seen by Voyager in 1979.

© Adrian Mann

SOLAR SYSTEM

Will the storms on Jupiter ever die out?

Astronomers have continuously observed the Great Red Spot (GRS), the largest Jovian storm, for 190 years. The elliptical area covered by clouds above the GRS has decreased recently, leading to predictions that the GRS could disappear in a decade. However, some remain convinced of its longevity because clouds are fickle, and the area and strength of the GRS may not be directly connected to the cloud coverage. Curiously, the area of GRS cloud coverage became rounder as it shrunk. If the storm itself is rounder, the winds of the GRS have strengthened, not weakened.

Jovian storms are sandwiched between counter-flowing jet streams; simulations show that this leads to their stabilisation. The GRS' lifetime likely depends on the longevity of the jet streams. Because those appear to be deep-seated within the atmosphere and tied to the convection that drives the Jovian weather, the GRS might survive for thousands of years.

Philip Marcus of the University of California, Berkeley

Did you know?

The GRS may have been observed by Robert Hooke in May 1664.

SOLAR SYSTEM

Can rocky planets gain rings?

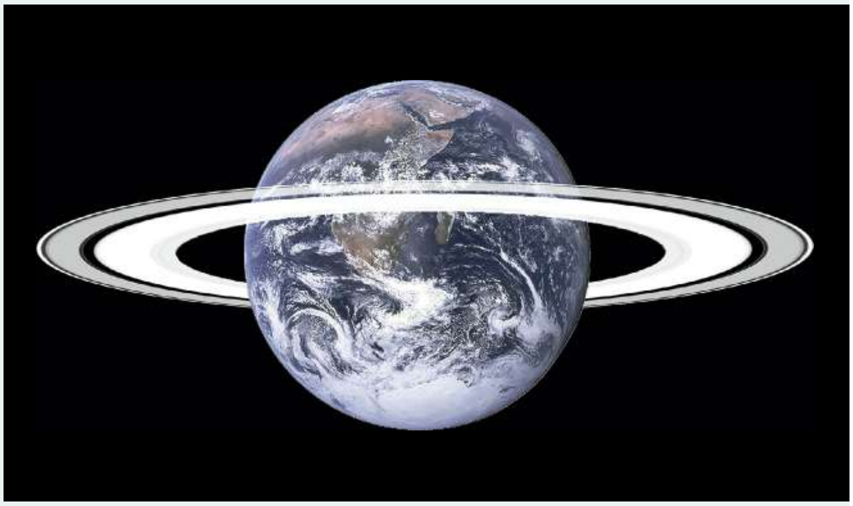
Jupiter, Saturn, Uranus and Neptune all have rings, while the inner, rocky planets do not. Scientists don't have any strong reasons to think rocky planets can never have rings, but their rings might be very different from those that we're used to in our Solar System. For example, Saturn's rings have an icy composition, but most rocky planets are much closer to their parent star. Similarly, ice material would not be able to exist here, so we would expect the rings to be composed of much rockier material.

In the future we will hopefully be able to search for these rings around other rocky planets elsewhere in the Milky Way galaxy. Amazingly, we now know of more than 4,000 planets, so there will be a lot of chances to search for these rings. Such rings would produce unique signatures as the planets pass in front of their parent stars and block the star's light. Unfortunately, none of these other rocky planets have conclusive evidence of rings, but this is mostly because the signal of rings is still very small. Astronomers will be able to better search for them in the future as our telescopes and instrumentation get more powerful.

Coming back to our Solar System, none of the inner, rocky planets have rings now, but did they have rings at any time in the past or future? Interestingly enough, Mars has two moons, and right now its inner moon, Phobos, is being pushed towards Mars from the gravitational interaction with the outer moon, Deimos. Astronomers can roughly estimate that if this continues, in about 50 to 100 million years Phobos will be so close to Mars that Mars' gravity will rip Phobos apart, producing rocky rings.

Dr Tony Piro is a staff astronomer at the Carnegie Observatories

Below: How would Earth appear if it had rings?



© NASA

© NASA

Left: Samantha Cristoforetti in her sleeping bag in the personal crew quarters of the ISS

SPACE EXPLORATION

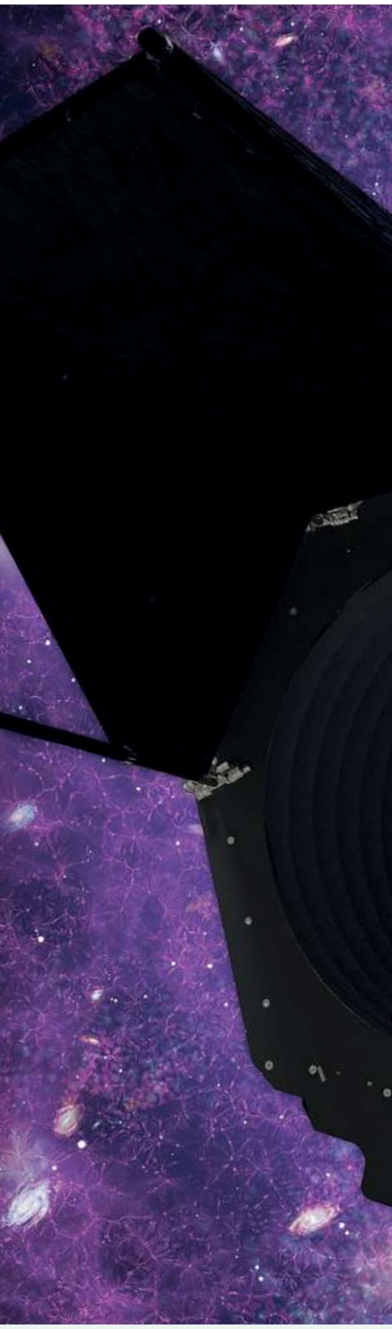
How do astronauts sleep with so many sunrises?

There isn't a whole lot of space to sleep on the International Space Station. Just a space for a sleeping bag, a few personal items and items of regular use. We have two laptops which can be used to read our emails and pull up our electronic schedule to see what activities we'll be doing the following day. There are also applications that allow us to talk on the phone to anyone on the planet. We can call our friends and family that way. We also have access to the internet.

I usually roll up the sleeping bag during the day so it's not in my way. When it's time to sleep I open it up and I can slide in. Some people leave them open, but if I'm cold I like to zip it up all the way, and I like to float when I'm sleeping. The booths are soundproof and well ventilated, because otherwise we'd be breathing a bubble of exhaled carbon dioxide and be deprived of oxygen.

Since there are 16 sunsets and sunrises every 24 hours, we work and sleep according to a daily time plan, looking to have eight hours of sleep at the end of each mission day. Using shutters or eyeshades keeps out sunlight, and an alarm clock or music broadcast by Mission Control on Earth will wake us.

Samantha Cristoforetti is an Italian European Space Agency (ESA) astronaut



ASTROPHYSICS

What would space sound like if we could hear it?

Let's pretend we can hear sounds in space like we can on Earth. Scientists have captured radio signals from space and translated them into sound through a process called Data Sonification. These eerie noises sound a lot like sound effects out of a 1950s science-fiction flick. They sound familiar because that's how we used to make space sound effects for movies - by recording shortwave radio signals as oscillations and using them as sound effects.

These are all electronic interpretations, so let's talk about sounds we can hear with our own ears. We know that space is vast and everything is very far away from each other. We also know that low frequencies travel further than high frequencies, so I would imagine that much of what we hear in space is at lower frequencies. We use this idea in movie sounds too: we often take the sound of wind moaning and pitch it down until it is a low rumble. It feels vast and empty. I also imagine we would hear the low thumps and rumbles of distant and long-past supernovae exploding, or black holes colliding.

On the higher frequencies you might detect the whistle of helium wind, or the intense oscillations of a pulsar. Maybe we might even get lucky enough to hear the ice of a comet vaporising into its coma as it passes by. But I would expect it to be fairly quiet in space, punctuated by the occasional gargantuan sound, as many of these events only happen once every century, or once in a million or billion years!

Greg King is a sound designer at King Soundworks whose credits include *Cosmos: Possible Worlds*

© NASA

HUNT FOR LIFE

Is Mars likely to have life on the surface?

On average, Mars is colder than your freezer and as dry as the driest deserts on Earth. Its thin atmosphere means the surface is bombarded by ultraviolet (UV) light from the Sun and other space radiation that destroys the building blocks of life.

Earth organisms can survive these extreme conditions for a time. But could life there get energy and nutrients to repair damage and replicate? Is it ever warm and wet enough?

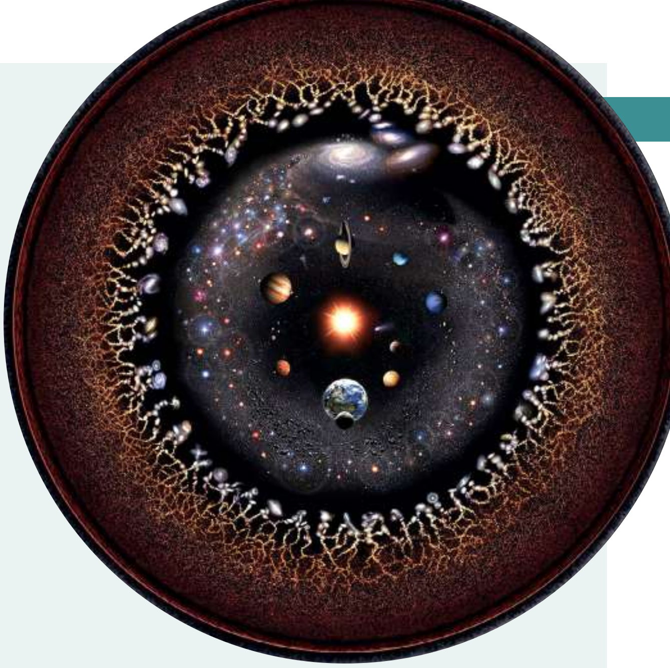
Mars surface microbes might obtain energy from chemicals or light. Tardigrades have UV-absorbing pigments, and it might be possible for life to get energy from UV. We also know that microbes in frozen Antarctic soils can get energy and nutrients from gases in the atmosphere present at very low levels. These same gases are present on Mars.

Some microbes can divide at temperatures similar to your freezer. Mars can get this warm during the day, but when it's warm the atmosphere holds a lot of water, and it is too dry for microbes to replicate. At night it cools off, the atmosphere cannot hold much water and it might be moist enough. However, it is too cold at that time.

We have not yet discovered any life capable of meeting all these challenges, yet scientists are continuing to look for life that might push the boundaries of what we know today. Even if life cannot survive on the surface of Mars, it's entirely possible that life as we know it could exist under the surface.

Christopher E. Carr teaches at the Georgia Institute of Technology

© NASA/ JPL-Caltech



Above: **The observable universe on a logarithmic scale**

Source: Wikipedia Commons © Pablo Carlos Budassi

ASTROPHYSICS

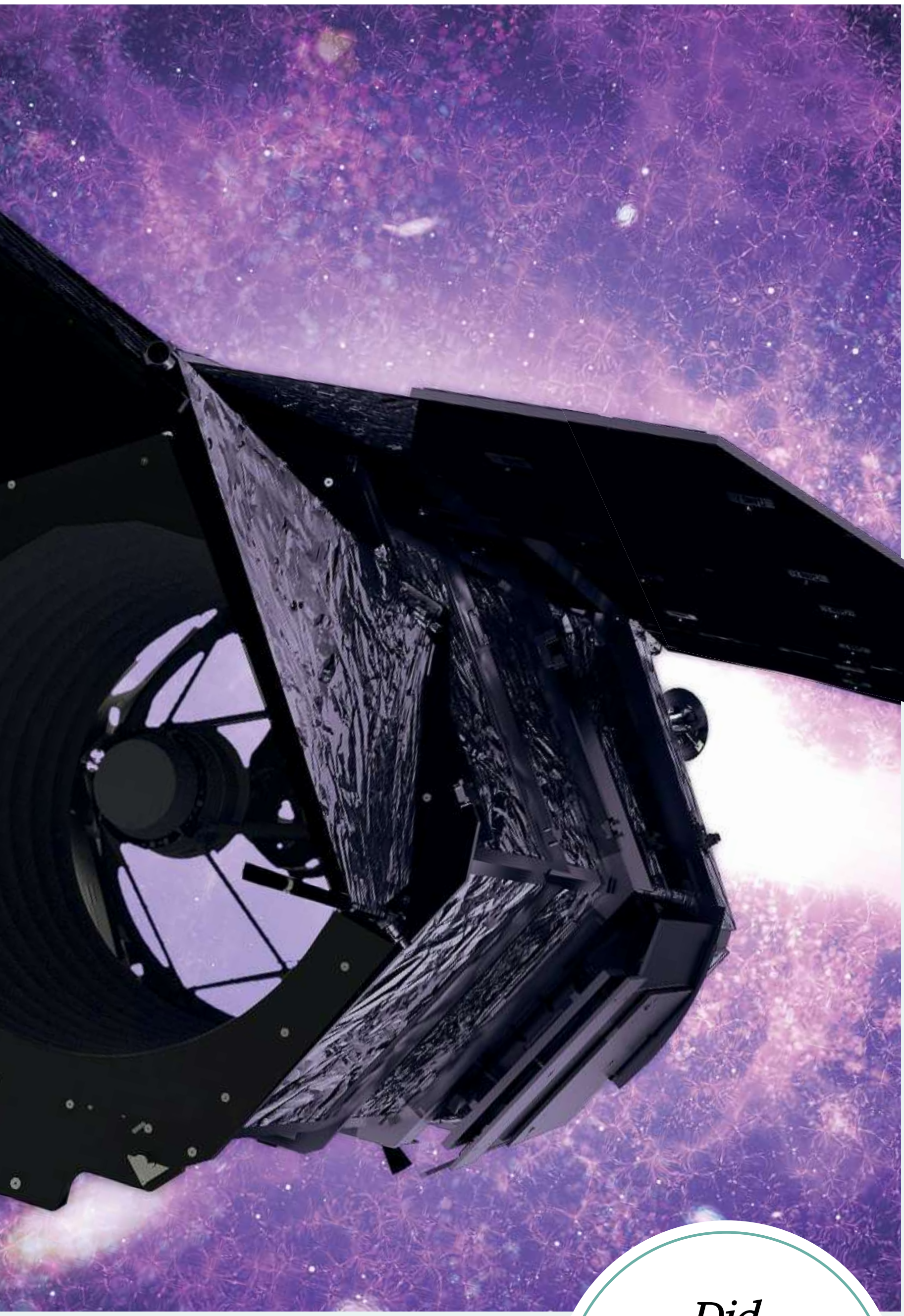
Where is the edge of the universe?

As far as we can tell, there is no edge to the universe. Space spreads out infinitely in all directions and galaxies fill all of the space throughout the entire infinite universe. This conclusion is reached by logically combining two observations. First, the part of the universe that we can see is uniform and flat on the cosmic scale. This means galaxy groups are spread out more or less evenly on the cosmic scale and the geometry of space-time is not curved or warped on the cosmic scale. As such, the universe does not wrap around and connect to itself like the surface of a sphere, which would lead to a finite universe.

The second observation is that our corner of the universe is not special or different, so all parts of the universe must be flat and uniform. As a consequence, the universe is infinite and has no edge. If you flew a spaceship in a straight line through space forever, you would never reach a wall, a boundary, an edge or even a region of the universe without galaxy groups.

But how can the universe have no edge if it was created in the Big Bang? If the universe started as finite in size, shouldn't it still be finite? The answer is that the universe did not start out as finite in size. The Big Bang was not like a bomb on a table exploding and expanding to fill a room with debris. The Big Bang did not happen at one point in the universe. It happened everywhere in the universe at once. For this reason the remnant of the Big Bang, the cosmic microwave background radiation, exists everywhere in space. Even today, we can look at any corner of the universe and see the cosmic microwave background radiation. The universe started out as an infinitely large object and has grown into an even larger infinitely large object, and is still expanding.

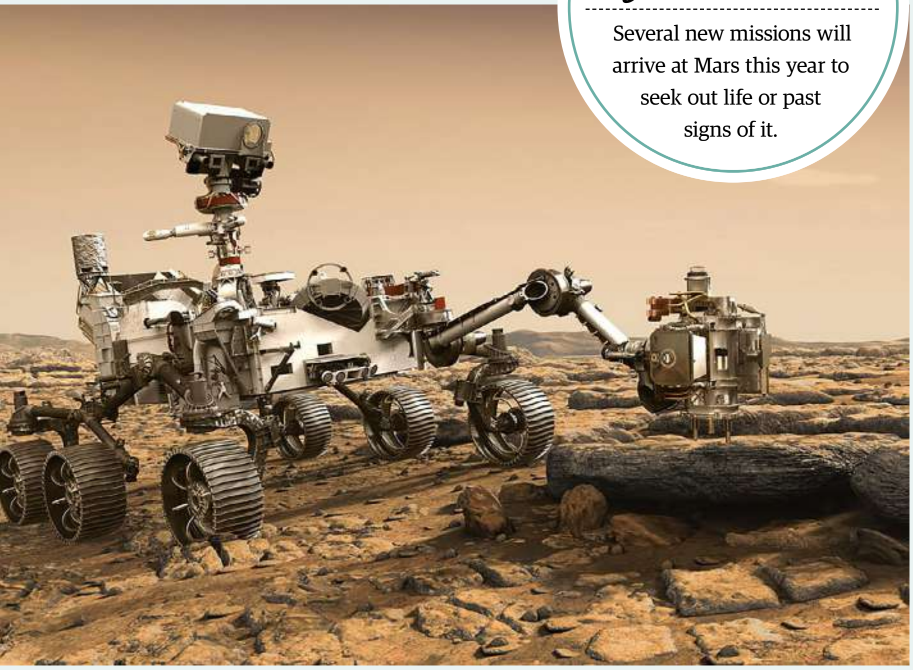
Dr Christopher S. Baird works at West Texas A&M University



Left: NASA's Roman Space Telescope is set to detect sound waves which once rippled through the primordial cosmic sea

Did you know?

Several new missions will arrive at Mars this year to seek out life or past signs of it.



Left: Finding life on the surface of Mars would prove to be a major breakthrough for science

STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

What's in the sky?

In this issue...

78 What's in the sky? Although the nights are getting shorter, there's still plenty of time to track down targets

80 Month's planets The elusive planet Mercury takes pride of place in the evening sky

84 Moon tour Use this little-known crater to track down a historic lunar landing site

85 Naked eye and binocular targets Enjoy some lovely sights in and around Gemini

86 Deep sky challenge Leo has many bright galaxies, but also hides other delights

88 The Northern Hemisphere Make the most of the February skies with these night-sky

90 Astrophotos of the month Our top pick of our reader's astrophotography

92 Telescope review Is the AstroMaster 102AZ the right telescope for you?

94 In the shops Our pick of the best products for astronomy and space fans

Red light friendly

In order to preserve your night vision, you should read our observing guide under red light

29 JAN

Mercury is well placed for observation in the evening sky, shining at magnitude -0.7

30 JAN

The Beehive open cluster (Messier 44) is well placed in Cancer, glowing at +3.1

18 FEB

Conjunction between the Moon and Mars in Aries

19 FEB

The Moon and Mars pass within 3°28′ of each other in Aries

© NASA/JPL-Caltech

19 FEB

Bode's Galaxy (Messier 81) is well placed for observation in Ursa Major

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

Source: Wikipedia Commons © Stuart Heggie

2 FEB

Asteroid 18 Melpomene reaches opposition in Cancer at magnitude +9.4

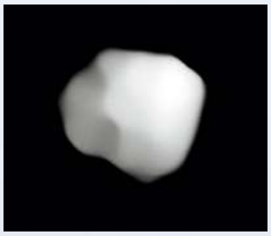
Source: Wilipedia ommons © Astronomical Institute of the Charles University, Josef Ďurech, Vojtěch Sidorin

19 FEB

Mercury reaches its highest point in the morning sky, shining at magnitude +0.1

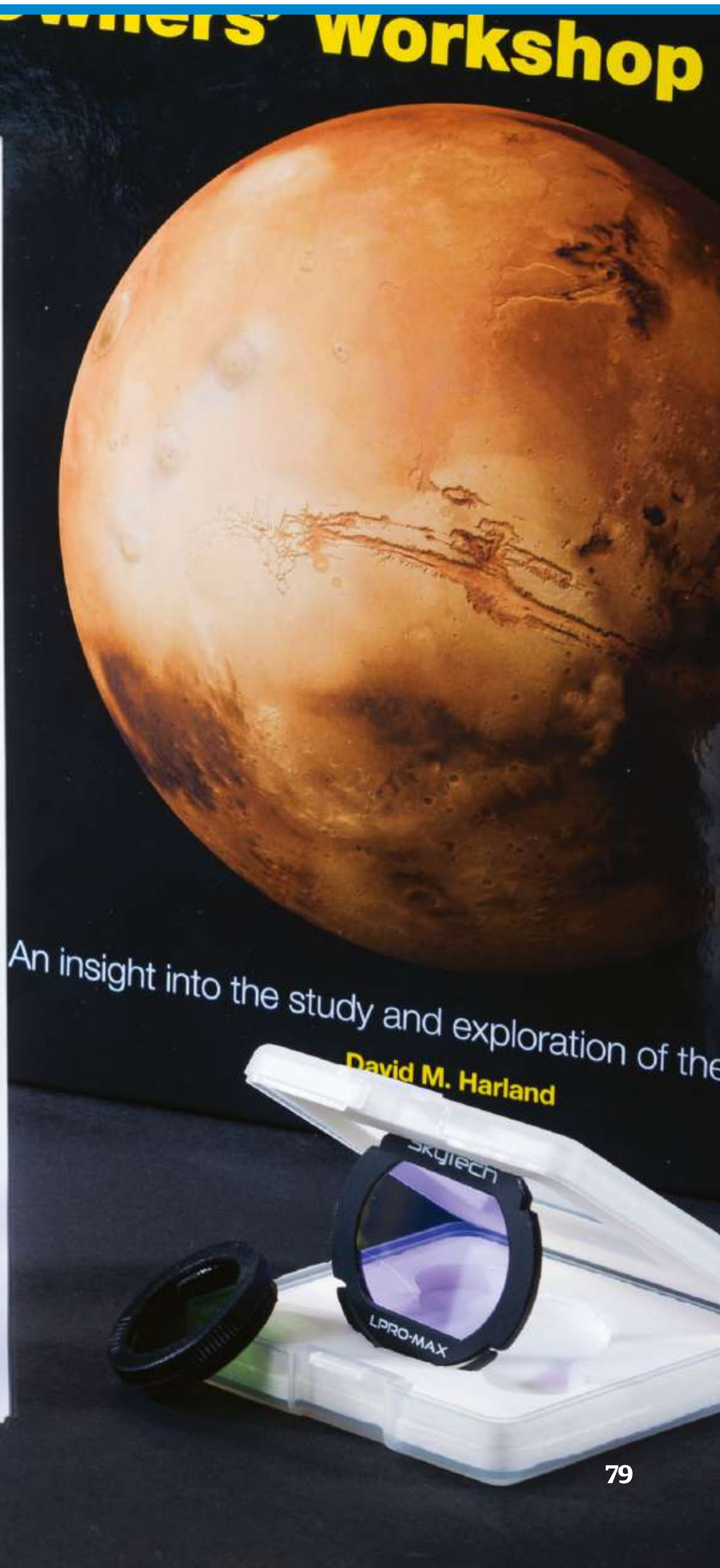
22 FEB

Asteroid 29 Amphitrite reaches opposition in Leo, glowing at magnitude +9.2



© ESO

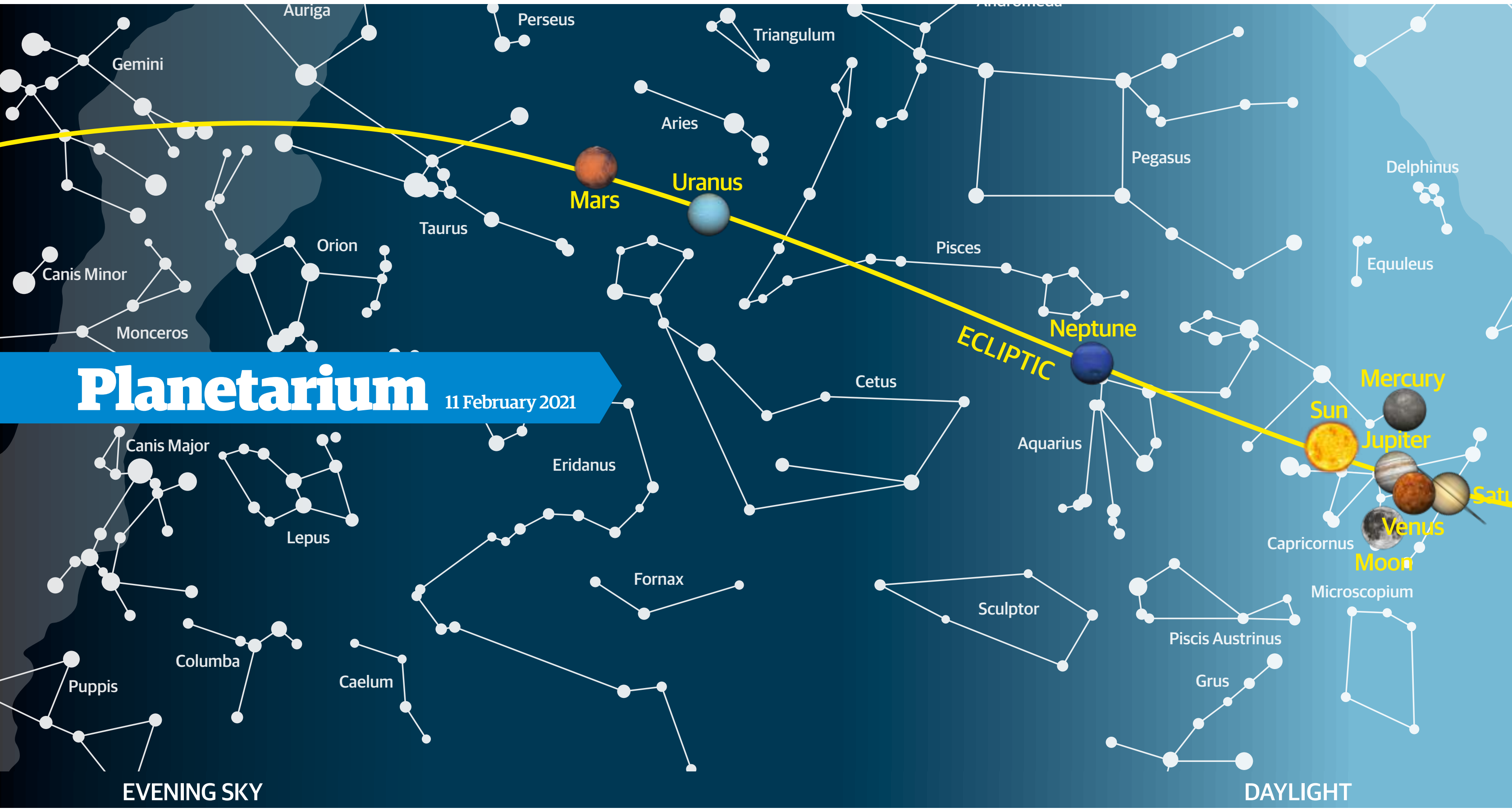
Naked eye
Binoculars
Small telescope
Medium telescope
Large telescope



STARGAZER

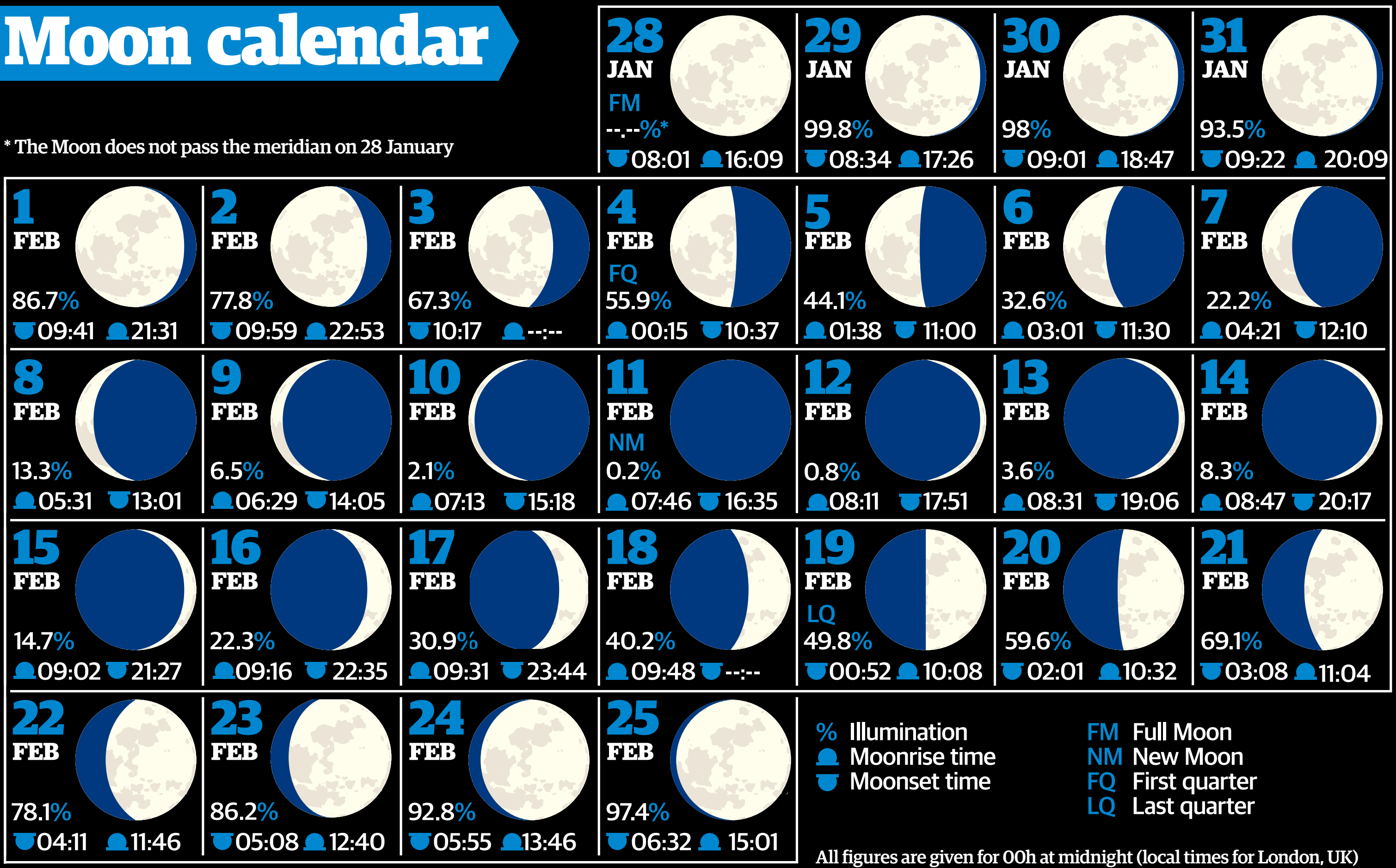
Planetarium

11 February 2021


Auriga
Perseus
Triangulum
Andromeda
Gemini
Aries
Pegasus
Delphinus
Mars
Uranus
Taurus
Orion
Pisces
Equuleus
Canis Minor
Monceros
Neptune
ECLIPTIC
Cetus
Mercury
Sun
Jupiter
Saturn
Aquarius
Canis Major
Eridanus
Venus
Moon
Capricornus
Lepus
Microscopium
Fornax
Sculptor
Piscis Austrinus
Columba
Caelum
Grus
Puppis
EVENING SKY
DAYLIGHT

Moon calendar

* The Moon does not pass the meridian on 28 January

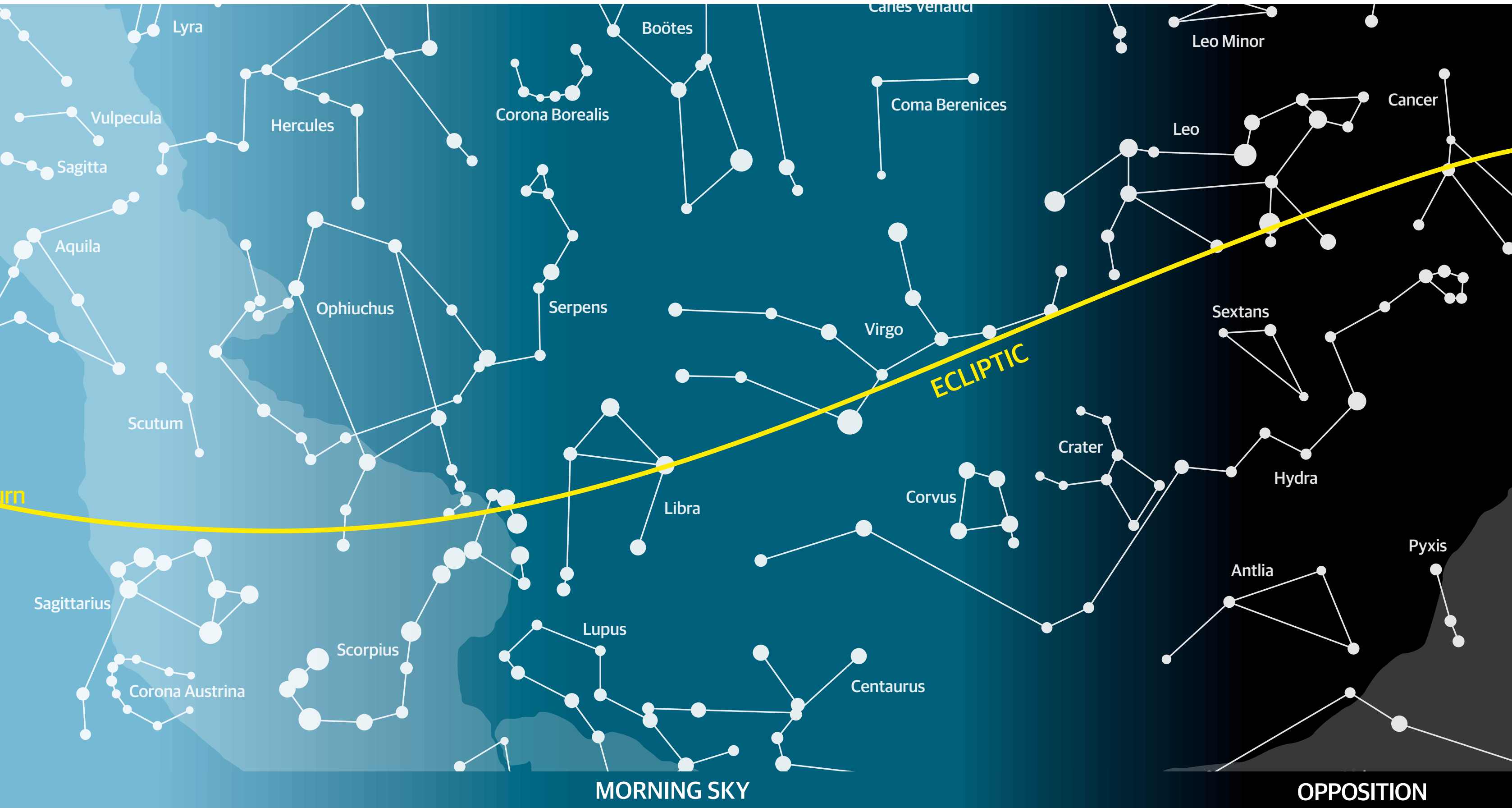


			28 JAN FM --.--%* ◒08:01 ◓16:09	**29 JAN** 99.8% ◒08:34 ◓17:26	**30 JAN** 98% ◒09:01 ◓18:47	**31 JAN** 93.5% ◒09:22 ◓20:09
1 FEB 86.7% ◒09:41 ◓21:31	**2 FEB** 77.8% ◒09:59 ◓22:53	**3 FEB** 67.3% ◒10:17 ◓--:--	**4 FEB** FQ 55.9% ◓00:15 ◒10:37	**5 FEB** 44.1% ◓01:38 ◒11:00	**6 FEB** 32.6% ◓03:01 ◒11:30	**7 FEB** 22.2% ◓04:21 ◒12:10
8 FEB 13.3% ◓05:31 ◒13:01	**9 FEB** 6.5% ◓06:29 ◒14:05	**10 FEB** 2.1% ◓07:13 ◒15:18	**11 FEB** NM 0.2% ◓07:46 ◒16:35	**12 FEB** 0.8% ◓08:11 ◒17:51	**13 FEB** 3.6% ◓08:31 ◒19:06	**14 FEB** 8.3% ◓08:47 ◒20:17
15 FEB 14.7% ◓09:02 ◒21:27	**16 FEB** 22.3% ◓09:16 ◒22:35	**17 FEB** 30.9% ◓09:31 ◒23:44	**18 FEB** 40.2% ◓09:48 ◒--:--	**19 FEB** LQ 49.8% ◒00:52 ◓10:08	**20 FEB** 59.6% ◒02:01 ◓10:32	**21 FEB** 69.1% ◒03:08 ◓11:04
22 FEB 78.1% ◒04:11 ◓11:46	**23 FEB** 86.2% ◒05:08 ◓12:40	**24 FEB** 92.8% ◒05:55 ◓13:46	**25 FEB** 97.4% ◒06:32 ◓15:01			

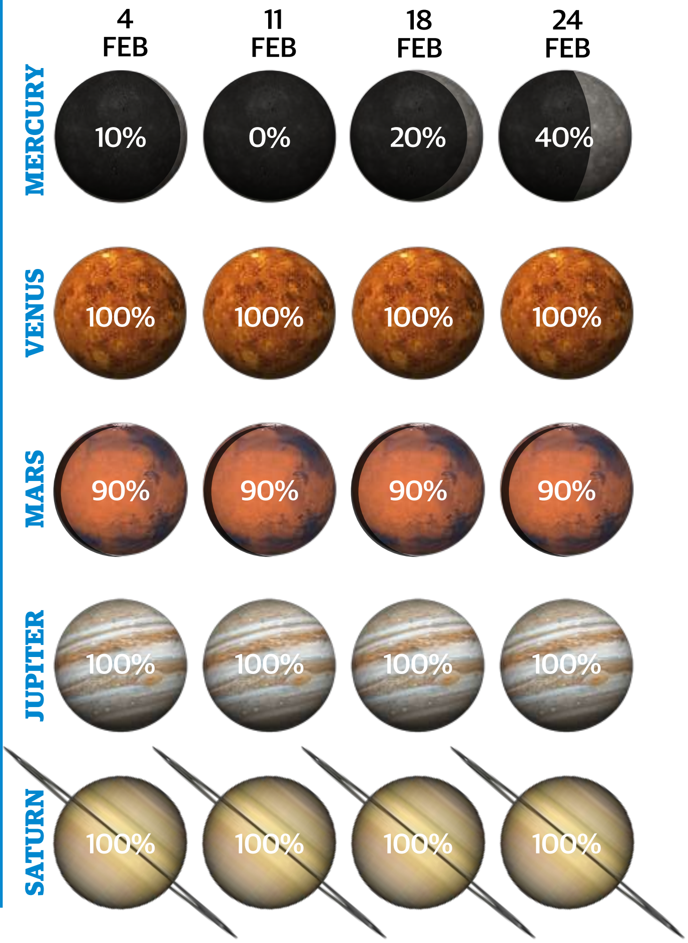
% Illumination
◓ Moonrise time
◒ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)


Canes Venatici
Lyra
Boötes
Leo Minor
Vulpecula
Hercules
Corona Borealis
Coma Berenices
Cancer
Leo
Sagitta
Aquila
Ophiuchus
Serpens
Virgo
Sextans
ECLIPTIC
Scutum
Crater
Hydra
Corvus
Libra
urn
Pyxis
Antlia
Sagittarius
Scorpius
Lupus
Corona Austrina
Centaurus
MORNING SKY
OPPOSITION

Illumination percentage



	4 FEB	11 FEB	18 FEB	24 FEB
MERCURY	10%	0%	20%	40%
VENUS	100%	100%	100%	100%
MARS	90%	90%	90%	90%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

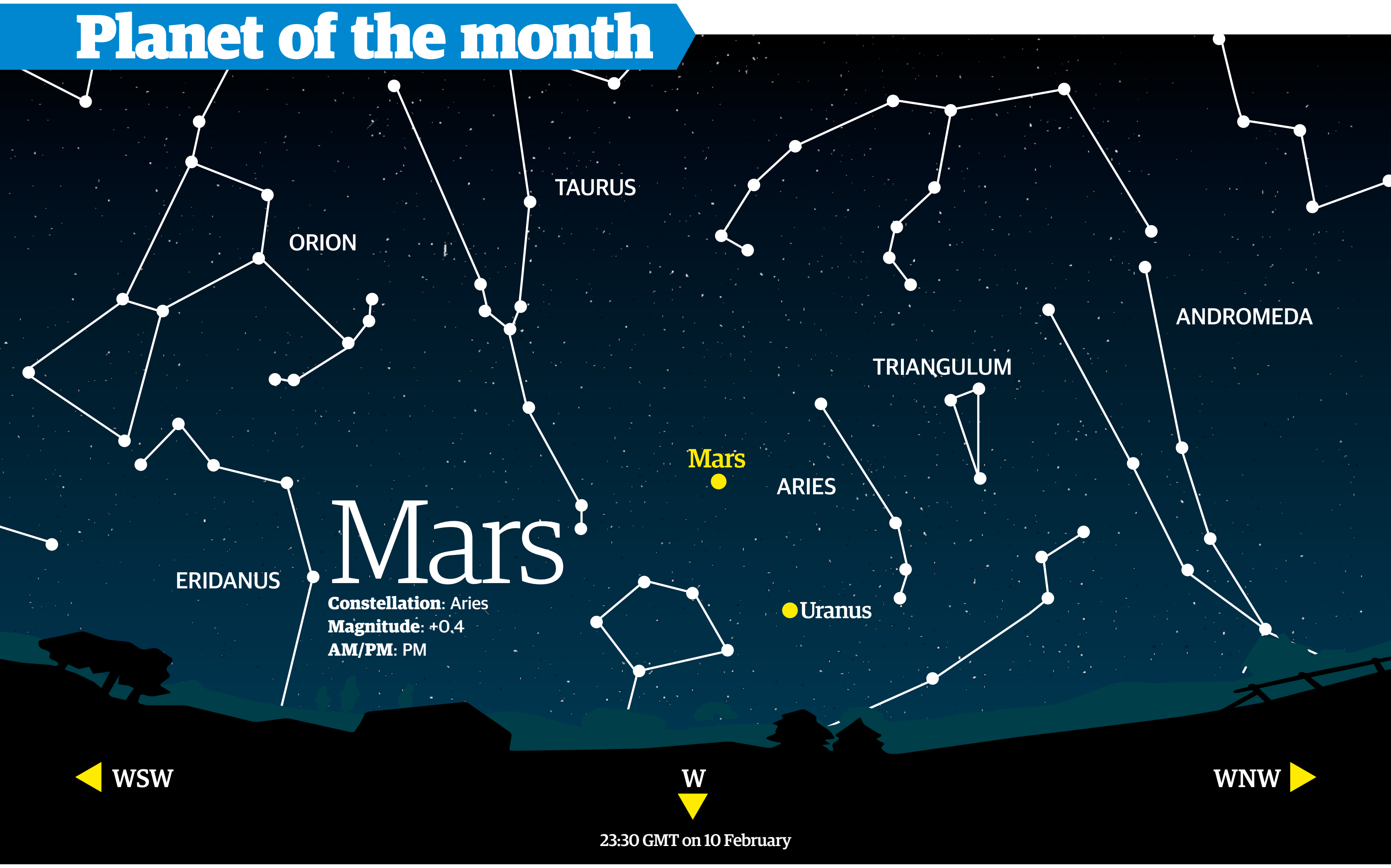
All rise and set times are given in GMT

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	28 JAN	21h 49m 59s	-12° 06' 19"	Capricornus	-0.1	08:18	18:20
	4 FEB	21h 43m 07s	-10° 38' 00"	Capricornus	+2.6	07:36	17:54
	11 FEB	21h 12m 42s	-12° 15' 42"	Aquarius	+4.2	06:46	16:47
	18 FEB	20h 51m 46s	-14° 41' 08"	Aquarius	+1.3	06:11	15:45
	24 FEB	20h 52m 53s	-15° 55' 39"	Aquarius	+0.4	05:56	15:16
VENUS	28 JAN	19h 43m 46s	-21° 46' 28"	Sagittarius	-3.9	07:09	15:17
	4 FEB	20h 20m 48s	-20° 15' 15"	Capricornus	-3.9	07:09	15:36
	11 FEB	20h 57m 00s	-18° 14' 47"	Capricornus	-3.9	07:05	15:57
	18 FEB	21h 32m 13s	-15° 48' 43"	Capricornus	-3.9	06:58	16:19
	24 FEB	22h 01m 39s	-13° 26' 14"	Aquarius	-3.9	06:51	16:39
MARS	28 JAN	02h 29m 17s	+16° 02' 37"	Aries	+0.4	10:29	01:30
	4 FEB	02h 44m 01s	+17° 15' 04"	Aries	+0.5	10:09	01:25
	11 FEB	02h 59m 21s	+18° 24' 44"	Aries	+0.6	09:49	01:20
	18 FEB	03h 15m 13s	+19° 30' 50"	Aries	+0.7	09:31	01:15
	24 FEB	03h 29m 13s	+20° 24' 01"	Taurus	+0.8	09:15	01:11
JUPITER	28 JAN	20h 45m 36s	-18° 33' 16"	Capricornus	-1.9	07:50	16:39
	4 FEB	20h 52m 21s	-18° 07' 12"	Capricornus	-1.9	07:27	16:21
	11 FEB	20h 59m 04s	-17° 40' 25"	Capricornus	-1.9	07:04	16:03
	18 FEB	21h 05m 41s	-17° 13' 05"	Capricornus	-2.0	06:40	15:45
	24 FEB	21h 11m 16s	-16° 49' 23"	Capricornus	-2.0	06:20	15:29
SATURN	28 JAN	20h 27m 50s	-19° 32' 08"	Capricornus	+0.6	07:39	16:15
	4 FEB	20h 31m 15s	-19° 20' 38"	Capricornus	+0.6	07:14	15:53
	11 FEB	20h 34m 38s	-19° 09' 04"	Capricornus	+0.7	06:48	15:30
	18 FEB	20h 37m 56s	-18° 57' 33"	Capricornus	+0.7	06:23	15:07
	24 FEB	20h 40m 41s	-18° 47' 50"	Capricornus	+0.7	06:01	14:47

This month's planets

The elusive planet Mercury takes pride of place in the evening sky, while Jupiter and Saturn are ready for early risers

Planet of the month



Mars

Constellation: Aries
Magnitude: +0.4
AM/PM: PM

23:30 GMT on 10 February

Mars is our Planet of the Month this month, not because it is particularly bright or well-placed, but because there's so much going to be happening there. Three space probes are due to arrive at Mars in February. After reaching Mars the United Arab Emirates' Hope orbiter, China's Tianwen-1 orbiter and lander and NASA's Perseverance rover will all send back a wealth of new information about the Red Planet, hopefully answering long-standing questions and solving many outstanding mysteries about the planet's past, present and future. Their results will also hopefully help NASA and other space agencies as they start thinking seriously about how to send astronauts to Mars, perhaps even in the next decade.

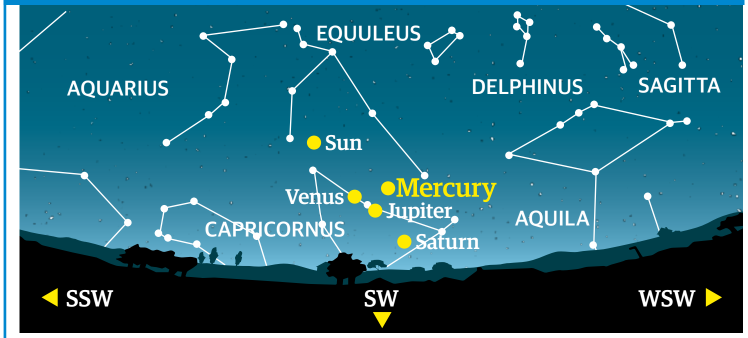
Mars' brilliant opposition of last October – when it blazed in the night sky like an orange lantern and observers all around the world enjoyed thrilling views of its ice caps and dusty plains through their telescopes – is now a fading memory. The Red Planet's brightness has dropped from dazzling minus magnitudes to a mere +0.4, but that means it is still almost as bright as Rigel, so it is still easily visible to the naked eye.

During the coming month Mars will already be high in the southeast as soon as the Sun sets and the sky begins to darken, looking like an orange 'star' to the upper right of Orion, and it won't set until the early hours of the next morning. As the month progresses Mars will drift steadily eastwards, heading for the neighbouring constellation of Taurus. By the end of our observing period Mars will actually have crossed the border into Taurus and will be just four degrees, or eight Moon widths, away from the starry knot of the Pleiades star cluster, also known as the 'Seven Sisters', shining to its lower right. If you have a pair of binoculars the cluster and planet should both fit into the same field of view, which will be a lovely sight.

By this time, if everything goes according to plan, NASA's Perseverance rover will have started to trundle around its landing site in Jezero crater. You'll be able to gaze up at the ruddy disc and picture the rover exploring the surface from afar.

This month's planets

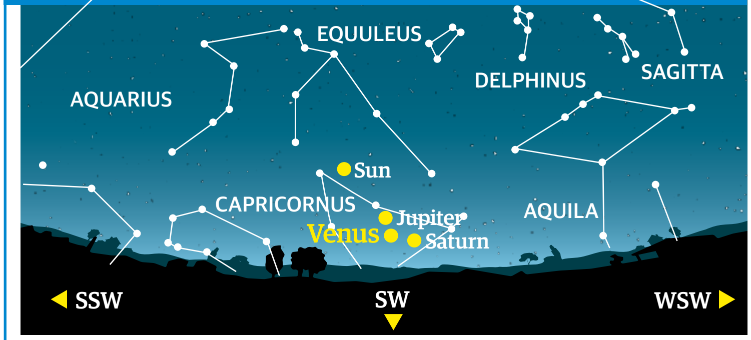
Mercury 15:00 GMT on 14 February


EQUULEUS
AQUARIUS
DELPHINUS
SAGITTA
Sun
Venus
Mercury
Jupiter
CAPRICORNUS
AQUILA
Saturn
SSW
SW
WSW

Constellation: Capricornus
Magnitude: +1.0
AM/PM: PM

Mercury, the closest planet to the Sun, will be an evening object at the start of our observing period, low in the southwest after sunset. Shining at +1.0, it will be visible to the naked eye, but you might need to scan the twilight sky with binoculars to spot it first, after which your eye will be drawn right to it.

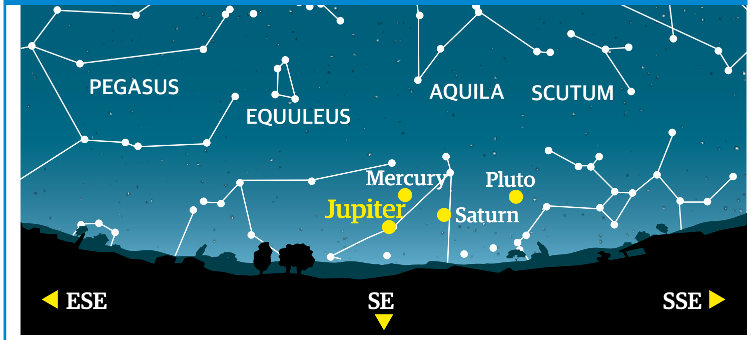
Venus 15:00 GMT on 10 February


EQUULEUS
AQUARIUS
DELPHINUS
SAGITTA
Sun
CAPRICORNUS
Jupiter
AQUILA
Venus
Saturn
SSW
SW
WSW

Constellation: Sagittarius
Magnitude: -3.9
AM/PM: PM

This will not be a good month at all for Venus observers. At the very start of our observing period it will be rising just a very short time before the Sun, lost in its glare, and as the days pass it will only move closer and closer to the Sun. Viewing conditions will be much better in March.

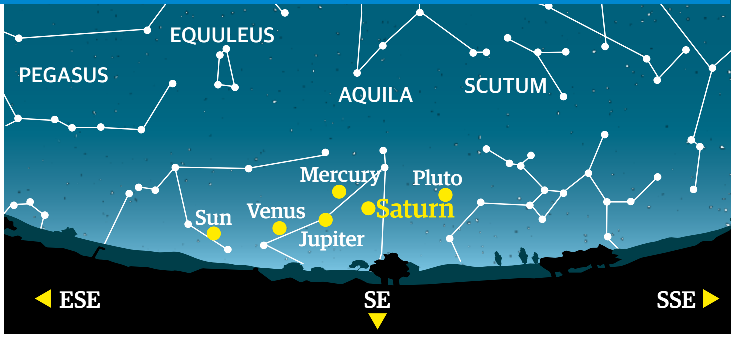
Jupiter 07:30 GMT on 18 February


PEGASUS
EQUULEUS
AQUILA
SCUTUM
Mercury
Pluto
Jupiter
Saturn
ESE
SE
SSE

Constellation: Capricornus
Magnitude: -2.0
AM/PM: AM

At the start of our observing period Jupiter will be too close to the Sun in the morning sky to be visible, but as the days and weeks pass it will begin to pull away from the Sun and its visibility will improve slightly. However, it will remain so close to the Sun in the sky that observing it will remain difficult.

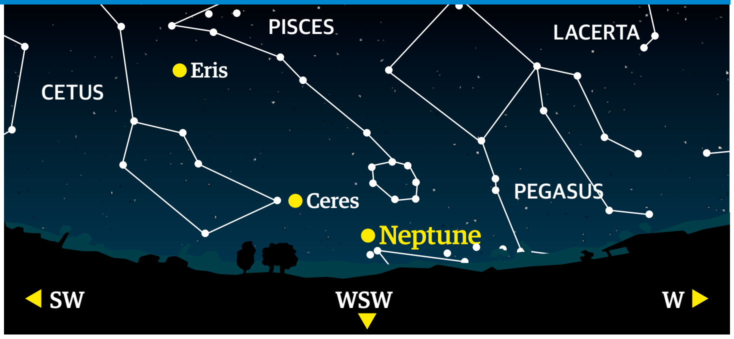
Saturn 07:30 GMT on 18 February


EQUULEUS
PEGASUS
AQUILA
SCUTUM
Mercury
Pluto
Sun
Venus
Saturn
Jupiter
ESE
SE
SSE

Constellation: Capricornus
Magnitude: +0.6
AM/PM: AM

Like its fellow gas giant Jupiter, ringed planet Saturn will be a morning object at the start of this month, but it will also be so close to the Sun that it will be difficult to see in a bright sky. However, by the end of February Saturn will be far enough away from the Sun to make it easier to see.

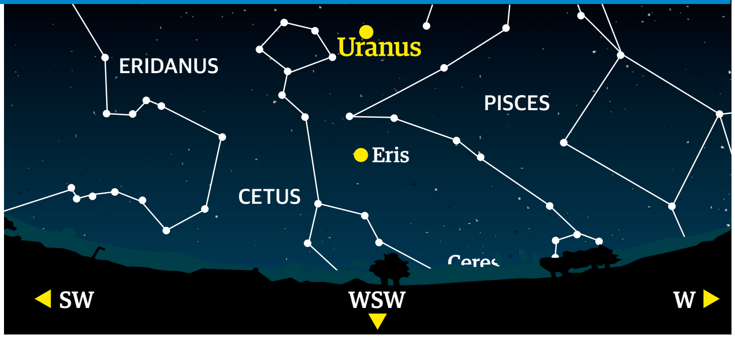
Neptune 22:30 GMT on 20 February


PISCES
LACERTA
CETUS
Eris
Ceres
PEGASUS
Neptune
SW
WSW
W

Constellation: Aquarius
Magnitude: +7.9
AM/PM: PM

Neptune, the most distant planet from the Sun, is visible in the evening sky this month, but there will only be a short observing window before it sets mid-evening. At magnitude +7.9 it is far too faint to see with the naked eye, and even through a pair of binoculars it will just look like a faint star.

Uranus 19:30 GMT on 18 February


ERIDANUS
Uranus
PISCES
Eris
CETUS
Ceres
SW
WSW
W

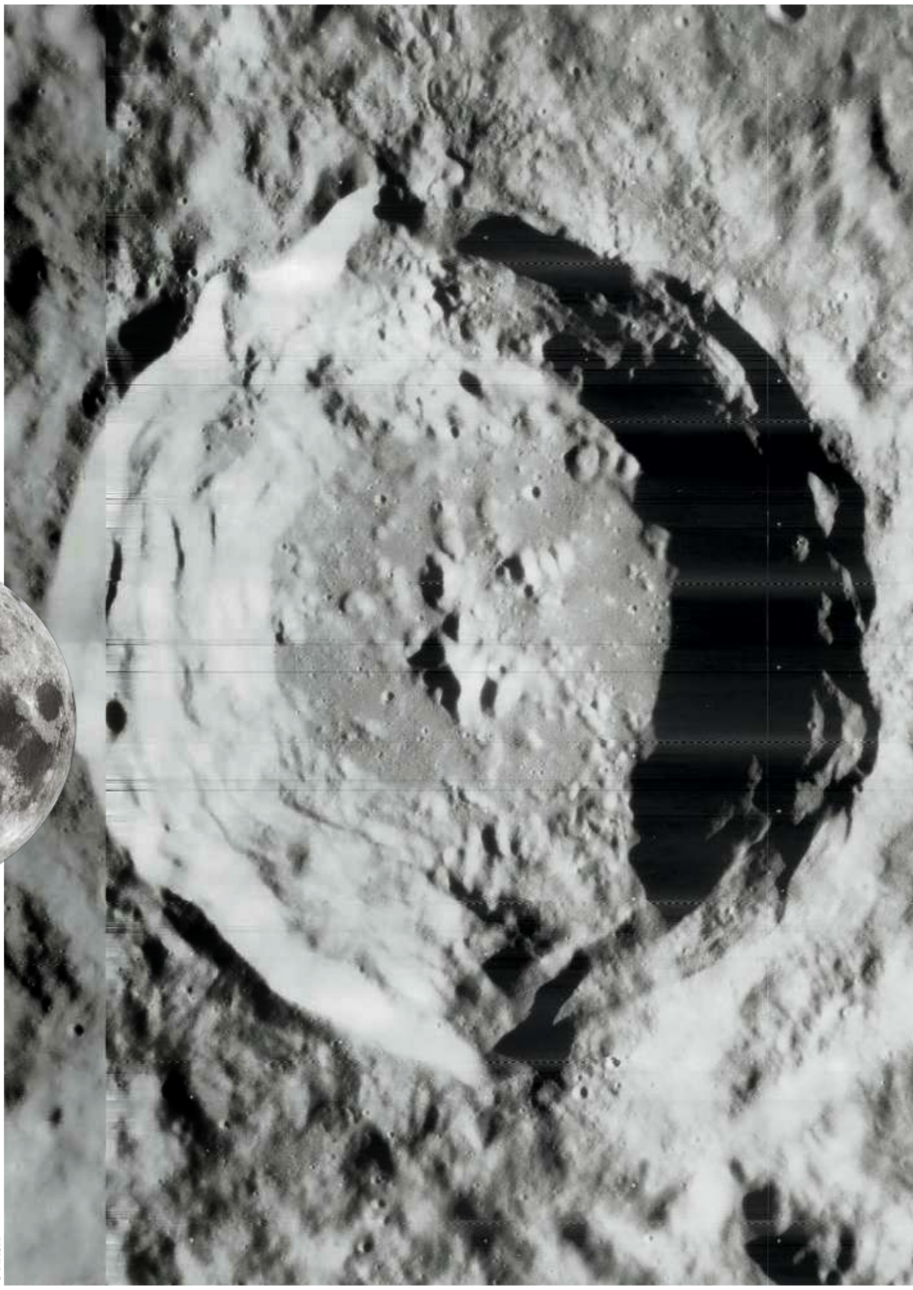
Constellation: Aries
Magnitude: +5.8
AM/PM: PM

Uranus will be an evening object during our observing period, shining just below 6th magnitude to the right of much brighter Mars and visible as soon as the sky begins to darken after sunset. However, you won't have long to see this distant ice giant world, as it will be setting not long after midnight.

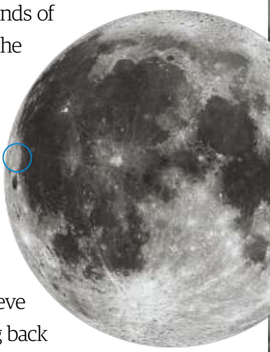
Moon tour

Cavalerius

Use this little-known crater to track down a historic lunar landing site



© NASA



Top tip!

The best time to see Cavalerius is when it is near or on the terminator, the line between lunar night and day.

Say 'lunar landing' and the crewed Apollo missions likely spring to mind, being the most iconic in lunar exploration. NASA's famous Apollo program was a technological and engineering triumph involving not just the few dozen astronauts who flew the spacecraft to the Moon and back, but hundreds of thousands of people working behind the scenes and out of the media spotlight, designing and building the spacecraft, the Saturn V rockets that launched them and everything else needed to land people on the Moon. But the Apollo landings would never have happened without the many robotic missions that preceded them, and 54 years ago, on 3 February 1966, the Russian Luna 9 probe became the first to achieve a controlled soft landing on the Moon, sending back information and images.

When the Russian probe landed on 3 February 1966 – using a then-revolutionary system of cushioning airbags – it bounced across the surface a few times and then, after coming to rest, opened up like a four-petalled flower and began transmitting information back to Earth. Almost nine hours of radio data was sent back, as well as three sets of images taken by its low-resolution TV camera – the first images ever sent back from the Moon's surface.

Russia had planned on releasing the images after a delay, but when someone worked out that Jodrell Bank was able to receive them there was a scramble to decode them. The *Daily Express* newspaper was able to get the correct equipment to the observatory, and when the images were decoded the newspaper published them on its front page in one of the greatest scoops of the Space Age. Luna 9 landed in the southwest of Oceanus Procellarum – in an unremarkable, hummocky plain which was later named Planitia Descensus in its honour. You can find its landing site using a large nearby crater as a guide.

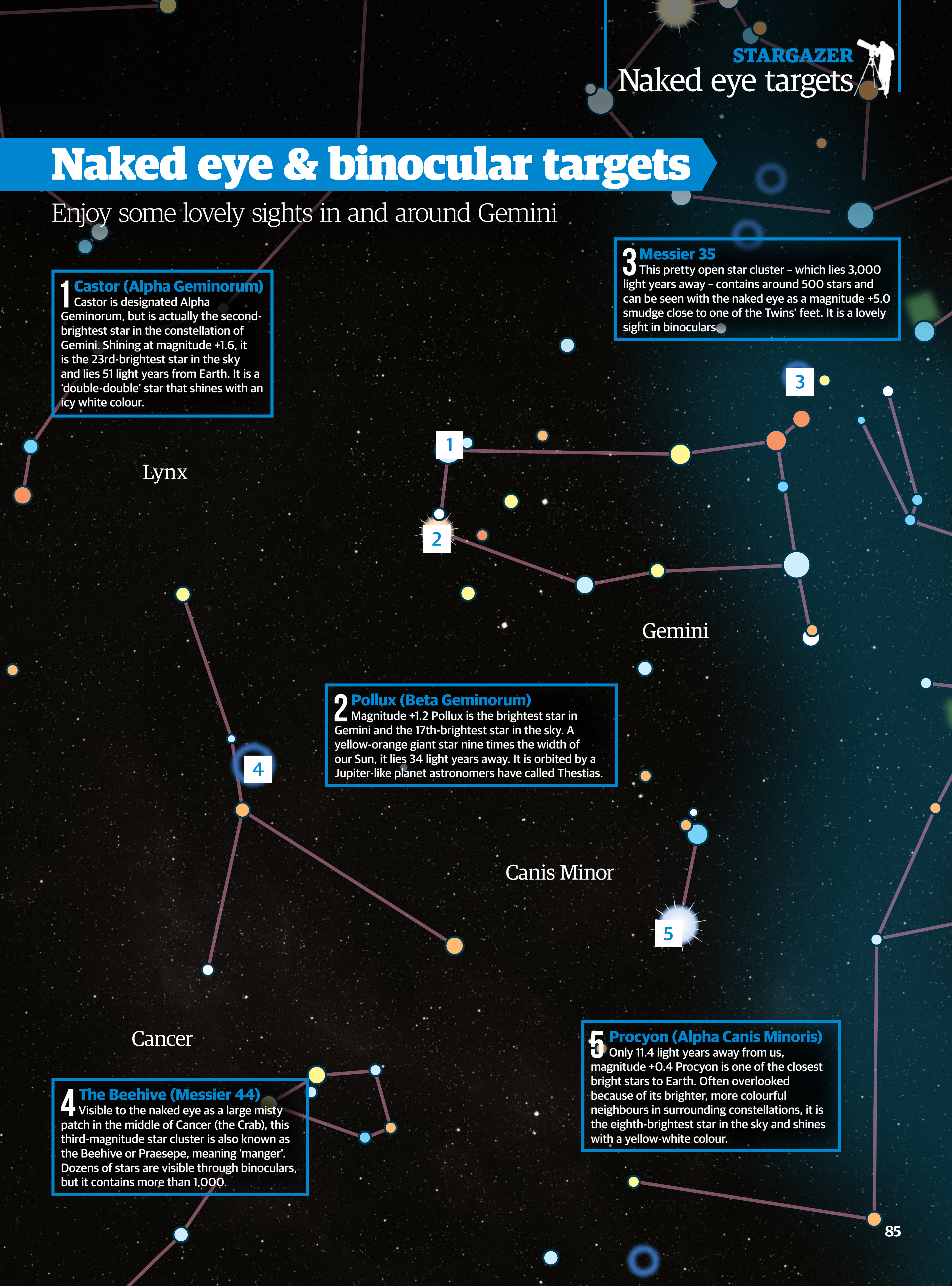
Although Cavalerius is overshadowed by the much larger and much older crater Hevelius which lies to its south, it is an interesting feature in its own right. Cavalerius is a classic lunar impact crater, roughly round in outline with terraced, slumped interior walls on its eastern and western sides and a small central peak on its rough floor which is pocked with a few small craters. 58 kilometres (36 miles) across and three kilometres (1.86 miles) deep, its northern and southern rims are both split by steep-walled valleys which would be much more prominent if the crater was nearer the middle of the Moon's face. Unfortunately, being so close to the limb means Cavalerius appears very foreshortened; those dramatic clefts are really only obvious when the crater is near the terminator and illuminated by the low Sun's slanting rays.

To find the Luna 9 landing site, centre Cavalerius in your telescope eyepiece and look for a much smaller, much sharper edged craterlet to its north. This is Cavalerius F, one of the craterlets blasted out of the Moon by the debris that rained down after Cavalerius itself was formed. The Luna 9 landing site lies at the end of a small, curved range of hills just to the south of this satellite crater.

So when exactly can you see this intriguing area of the Moon this month? At the start of our observing period the Moon is almost full, and Cavalerius will be close to the terminator, lit at a low angle, so its features will really stand out. But by 29 January the Moon will be full, and with the Sun now overhead Cavalerius will blend back into the background. By 7 February the terminator will begin to approach it, but by then the Moon will be a waning crescent in the predawn sky, so it won't be visible for long before sunrise. Cavalerius will not reappear until after the end of our observing period.

Naked eye & binocular targets

Enjoy some lovely sights in and around Gemini



1 Castor (Alpha Geminorum)

Castor is designated Alpha Geminorum, but is actually the second-brightest star in the constellation of Gemini. Shining at magnitude +1.6, it is the 23rd-brightest star in the sky and lies 51 light years from Earth. It is a 'double-double' star that shines with an icy white colour.

2 Pollux (Beta Geminorum)

Magnitude +1.2 Pollux is the brightest star in Gemini and the 17th-brightest star in the sky. A yellow-orange giant star nine times the width of our Sun, it lies 34 light years away. It is orbited by a Jupiter-like planet astronomers have called Thestias.

3 Messier 35

This pretty open star cluster – which lies 3,000 light years away – contains around 500 stars and can be seen with the naked eye as a magnitude +5.0 smudge close to one of the Twins' feet. It is a lovely sight in binoculars.

4 The Beehive (Messier 44)

Visible to the naked eye as a large misty patch in the middle of Cancer (the Crab), this third-magnitude star cluster is also known as the Beehive or Praesepe, meaning 'manger'. Dozens of stars are visible through binoculars, but it contains more than 1,000.

5 Procyon (Alpha Canis Minoris)

Only 11.4 light years away from us, magnitude +0.4 Procyon is one of the closest bright stars to Earth. Often overlooked because of its brighter, more colourful neighbours in surrounding constellations, it is the eighth-brightest star in the sky and shines with a yellow-white colour.

NGC 3628

© ESO

Deep sky challenge

The borders of Leo, the Lion

Famous for containing many bright galaxies, Leo also hides some lesser known deep-sky delights

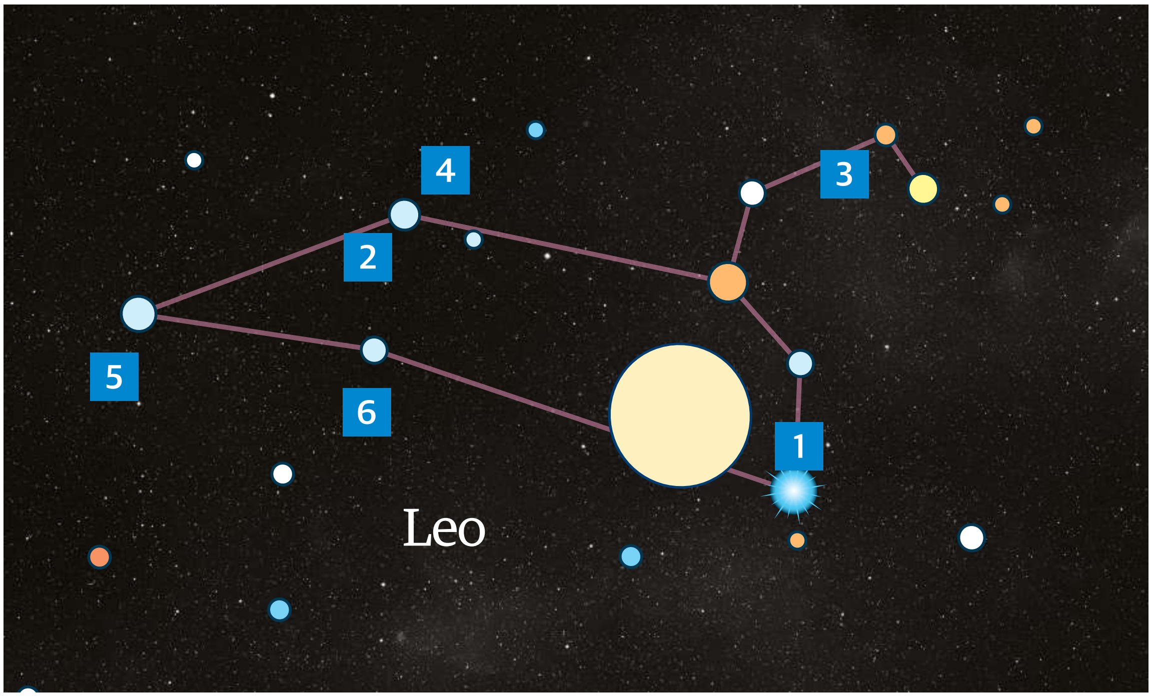
Easy to spot because of its 'sickle' asterism, the zodiacal constellation of Leo is visible in the sky all through the night now. Among deep-sky observers it is famous for containing many bright and beautiful galaxies, such as Messier 65, Messier 66 and NGC 3628, which are visible in small telescopes and even binoculars. But owners of medium- or large-aperture telescopes who sweep the constellation with their frosted instruments on these bitterly cold but sparkling clear February nights - especially if the Moon is absent from the sky - can see many more fascinating objects, and not just galaxies.

Look just 17 arcminutes north of Regulus, Leo's brightest star, and you'll see the Leo I dwarf galaxy as an elongated, misty patch. Leo II, another lovely looking elliptical galaxy, can be found over at the far end of the constellation. Beneath it, a little to the right of Denebola, the elliptical galaxy NGC 3872 is also a very attractive sight.

But Leo is also home to some very pretty spiral galaxies too, such as NGC 3596 and NGC 3455. As we approach spring, treat yourself to a tour of some of Leo's 'off the beaten track' deep-sky objects. You won't be disappointed.

Messier 66

© ESO



1 Leo I

This lovely tenth-magnitude elliptical dwarf galaxy looks like a smoky, oval patch in a medium-aperture telescope's high-powered eyepiece. It lies around 815,000 light years from our Sun.

2 NGC 3632

Located close to the star Zosma, this spiral galaxy glows at magnitude +10.6 and is seen well as a round, misty patch in medium-aperture instruments. It is a member of the Leo II group of galaxies.

3 NGC 3098

This 12th-magnitude edge-on spiral galaxy is a challenge even for large telescopes on perfect nights. At high magnification it closely resembles a smaller, fainter version of the more famous Needle Galaxy, NGC 4565.

4 Leo II

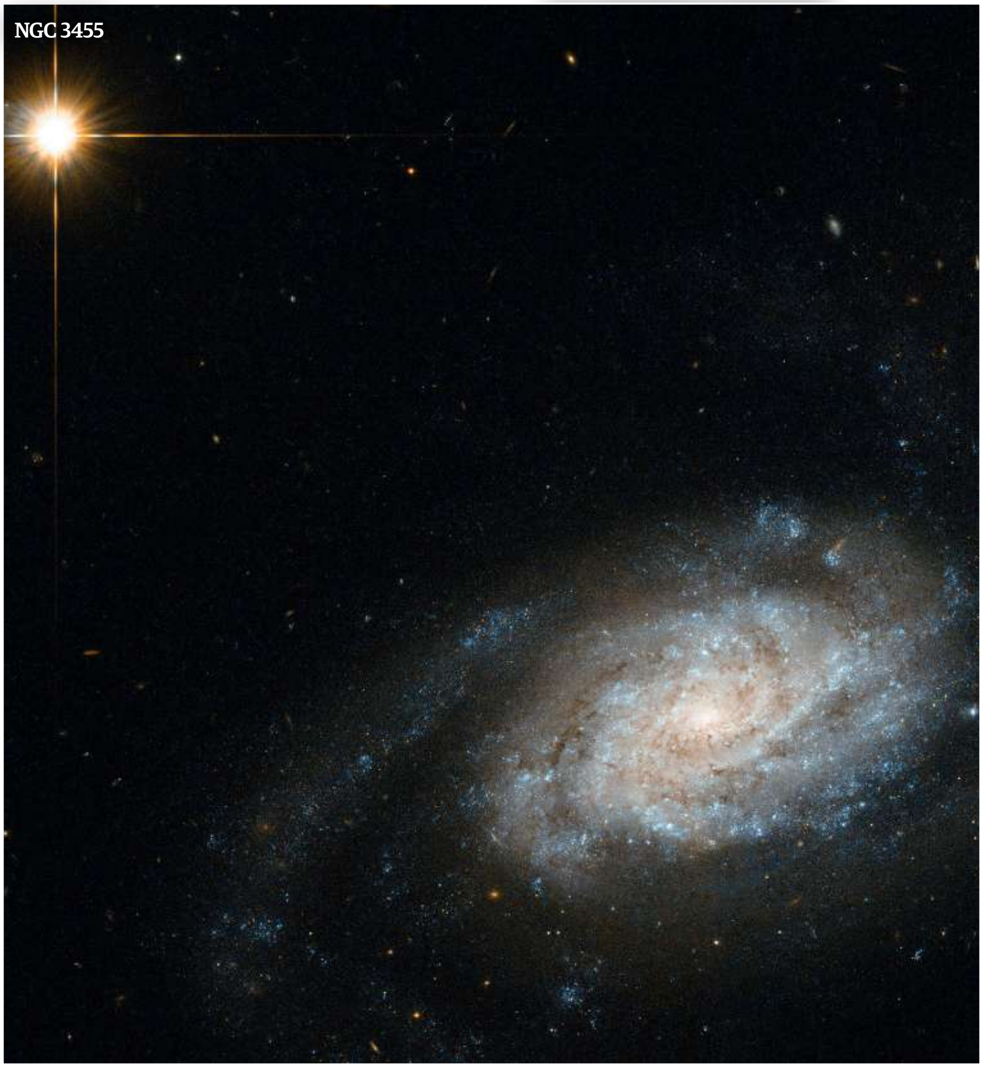
This dwarf elliptical galaxy lies 690,000 light years away and is of 11th magnitude. High magnifications will reveal hints of mottling in its centre. Leo II seems to consist largely of older metal-poor stars.

5 NGC 3872

Little more than a tiny, oval-shaped smudge even in large-aperture telescopes on dark nights, this elliptical galaxy has a magnitude of just above 12 and lies more than 157 million light years away from us.

6 NGC 3596

This 12th-magnitude spiral galaxy, 60 million light years away, is a very attractive sight in large telescopes on nights of good seeing, with two tightly wound spiral arms curving around a bright central core.


NGC 3455

© ESA/Hubble & NASA

> "TREAT YOURSELF TO A TOUR OF SOME OF LEO'S 'OFF THE BEATEN TRACK' DEEP-SKY OBJECTS. YOU WON'T BE DISAPPOINTED"

The Northern Hemisphere

Make the most of the February skies with these night-sky gems

The Dog Star, Sirius - which shines at magnitude -1.46 in Canis Major - is an unmissable sight for those who are content with gazing at the sky without the need for binoculars or a telescope. Meanwhile, red supergiant Betelgeuse on the shoulder of Orion is also an easy target for the naked eye, glowing with a reddish hue. If you have a pair of binoculars of at least 10x50 magnification, then sweep across the stellar members that make up the Pleiades (Messier 45) and the Hyades star clusters. If you have a telescope with at least a small aperture, then head to the tip of Taurus' bottom horn and you should be able to spot a stunning supernova remnant - the Crab Nebula (Messier 1) - under favourable night-sky conditions.

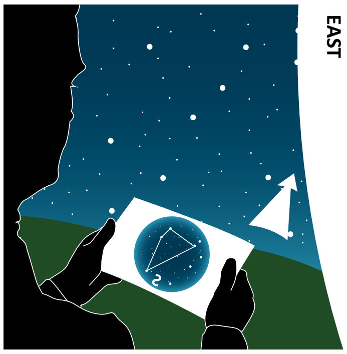
Using the sky chart

This chart is for use at 22:00 (GMT) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.



Magnitudes

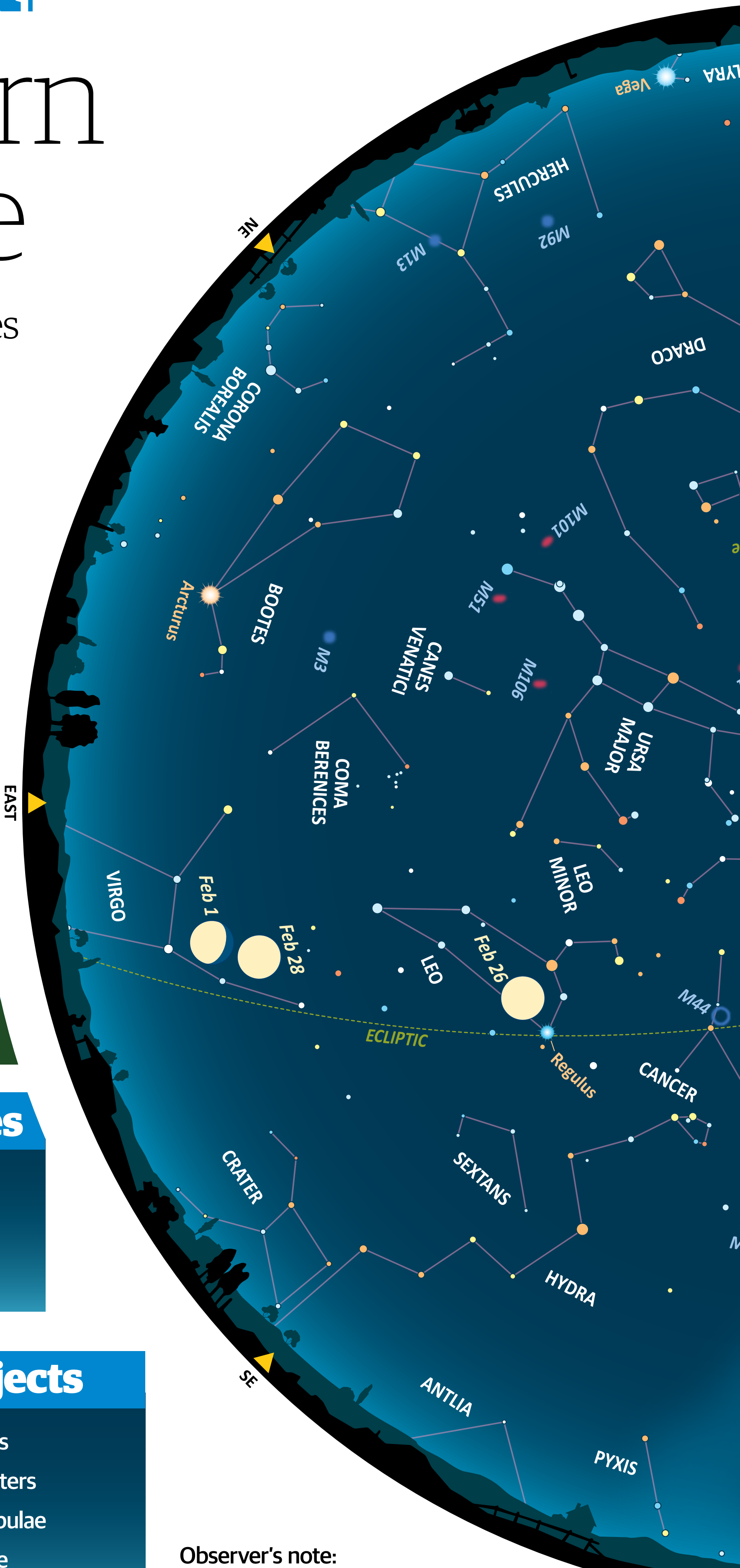
● Sirius (-1.4)
● -0.5 to 0.0
● 0.0 to 0.5
● 0.5 to 1.0
● 1.0 to 1.5
● 1.5 to 2.0
● 2.0 to 2.5
● 2.5 to 3.0
● 3.0 to 3.5
● 3.5 to 4.0
● 4.0 to 4.5
● Fainter
◉ Variable star

Spectral types

● O-B
● A
● F
● G
● K
● M

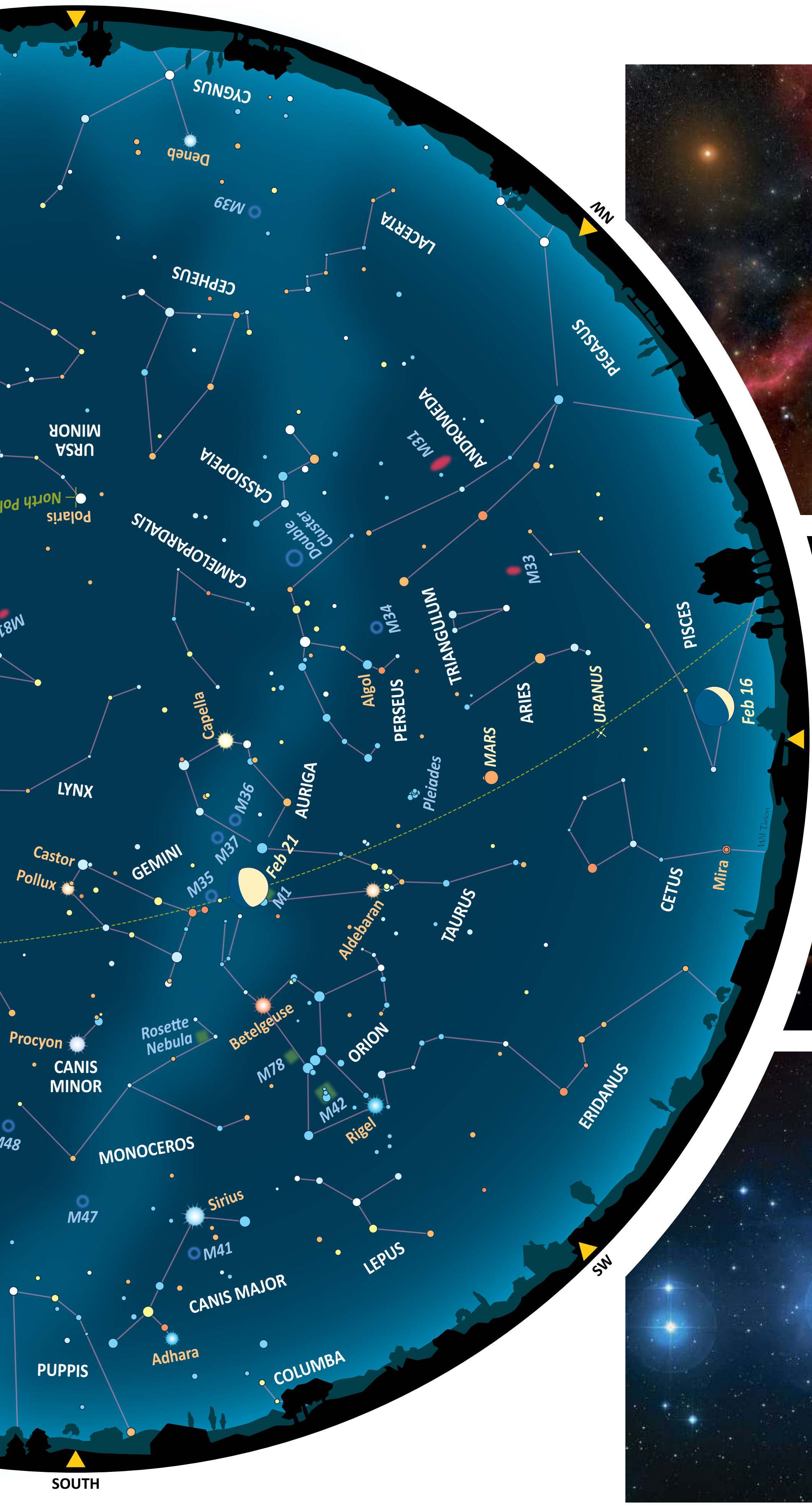
Deep-sky objects

○ Open star clusters
● Globular star clusters
🟩 Bright diffuse nebulae
○ Planetary nebulae
● Galaxies


Vega
LYRA
HERCULES
M92
M13
NE
DRACO
CORONA BOREALIS
M101
Arcturus
BOOTES
M51
M3
CANES VENATICI
M106
URSA MAJOR
COMA BERENICES
EAST
VIRGO
Feb 1
Feb 28
LEO MINOR
LEO
Feb 26
M44
ECLIPTIC
Regulus
CANCER
CRATER
SEXTANS
HYDRA
SE
ANTLIA
PYXIS

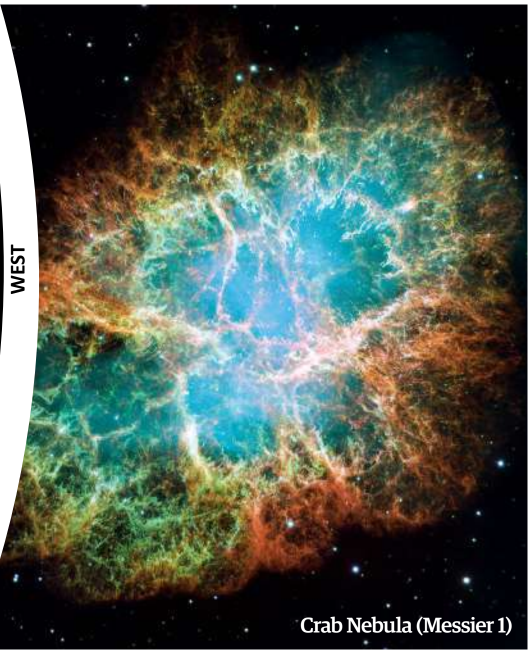
Observer's note:
The night sky as it appears on 17 February 2021 at approximately 22:00 (GMT)

The Northern Hemisphere


NORTH
CYGNUS
Deneb
M39
LACERTA
CEPHEUS
NW
PEGASUS
ANDROMEDA
M31
URSA MINOR
CASSIOPEIA
North Pole
Polaris
Double Cluster
CAMELOPARDALIS
M81
M33
M34
TRIANGULUM
PISCES
Algol
PERSEUS
ARIES
URANUS
Feb 16
WEST
Capella
LYNX
AURIGA
M36
Pleiades
MARS
M37
Feb 21
Castor
GEMINI
Pollux
M35
M1
Aldebaran
TAURUS
CETUS
Mira
Procyon
Rosette Nebula
Betelgeuse
CANIS MINOR
M78
ORION
M42
Rigel
ERIDANUS
M48
MONOCEROS
M47
Sirius
M41
LEPUS
SW
CANIS MAJOR
PUPPIS
Adhara
COLUMBA
SOUTH
Wil Tirion

Betelgeuse (Alpha Orionis) in the constellation of Orion

Source: Wikipedia Commons © Rogelio Bernal Andreo



Crab Nebula (Messier 1)

© NASA, ESA

The Pleiades (Messier 45)

© NASA, ESA

Astroshots of the month

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**

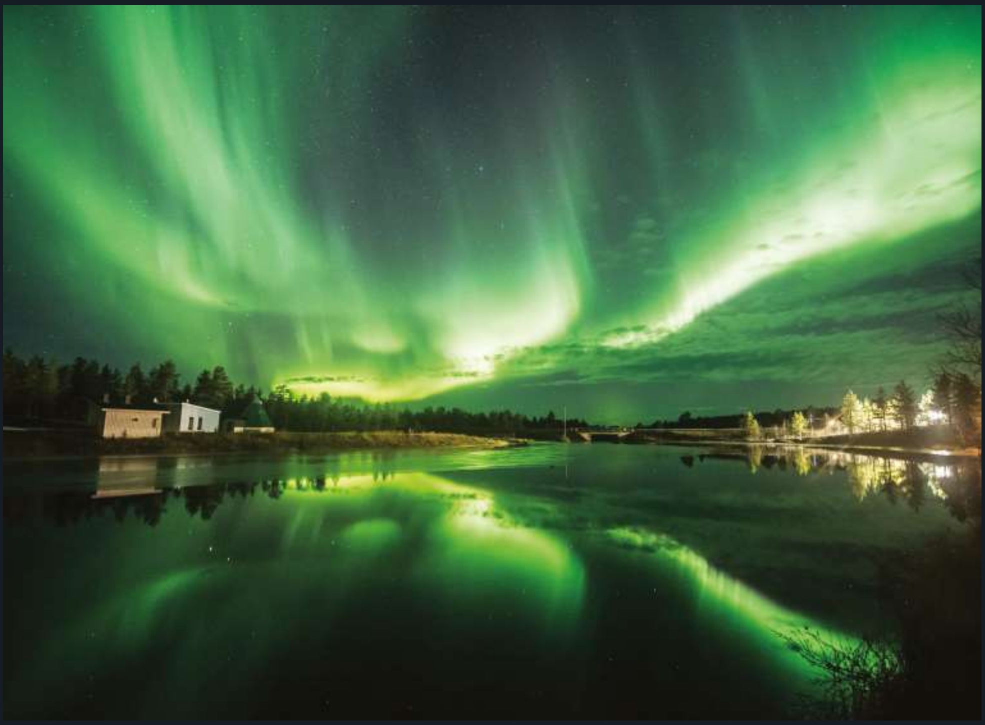
Ollie Taylor

Location: Isle of Portland, Dorset

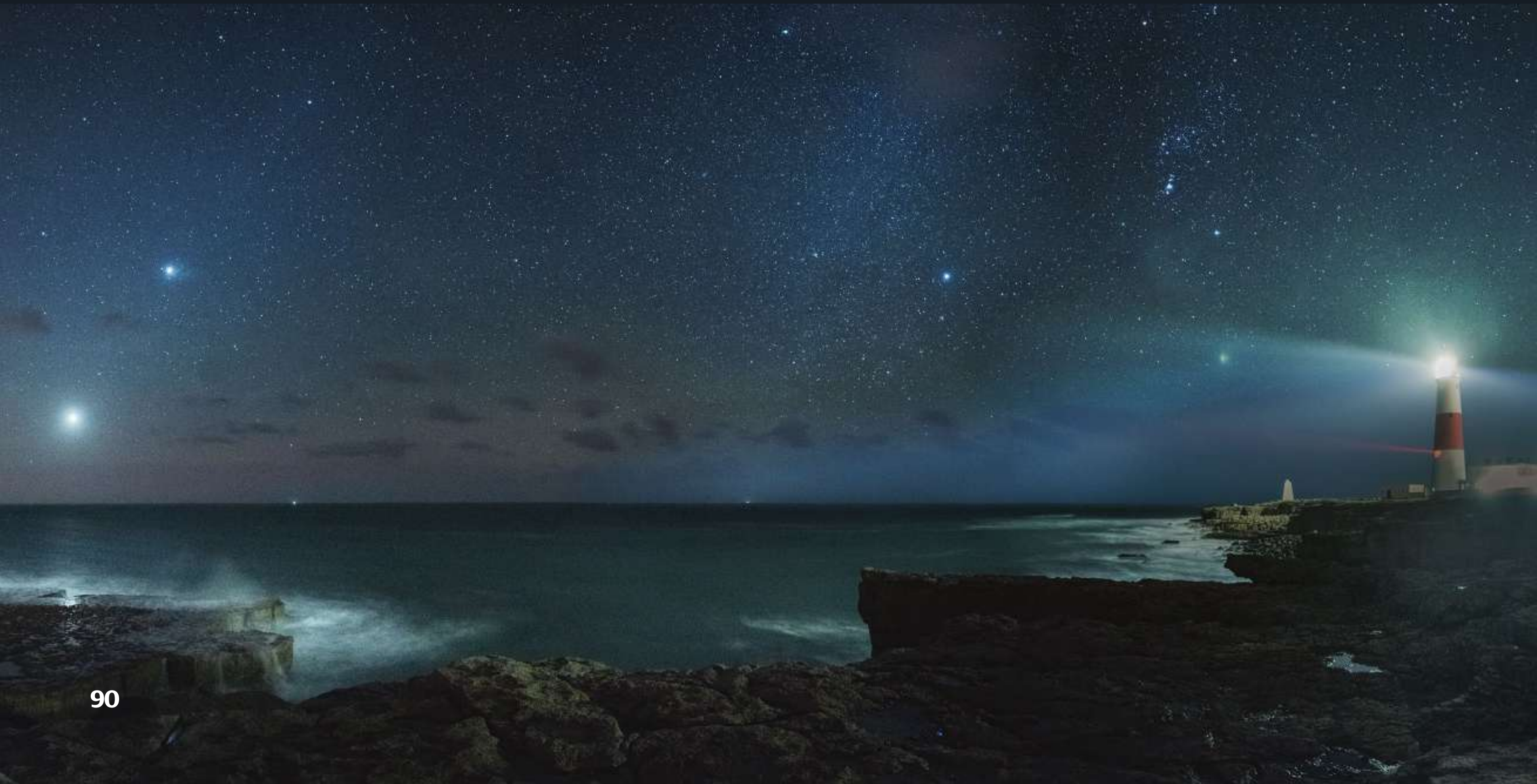
"Using my DSLR camera on a dark November night on the Isle of Portland, I captured Venus, Mars and Jupiter as they rose in a diagonal line above the horizon. One of the brightest stars in the night sky and in the constellation of Leo, Regulus, can also be seen aligning at the top of the image.

"Luckily, and due to the clear horizon near Portland, which allows you to look far out into the British Channel, Venus was so bright that it cast reflections in the sea and rock pools. It will be decades before these celestial objects align again.

"I also love shooting aurorae, and while I was out in Finland I managed to capture the northern lights. I have been photographing landscapes with the emphasis on the night sky since late winter 2011 after shooting the aurora in Iceland – something I had longed to do for years."



Right: Aurora borealis, Finland



Right: Venus, Mars and Jupiter, Portland Bill, Dorset, UK

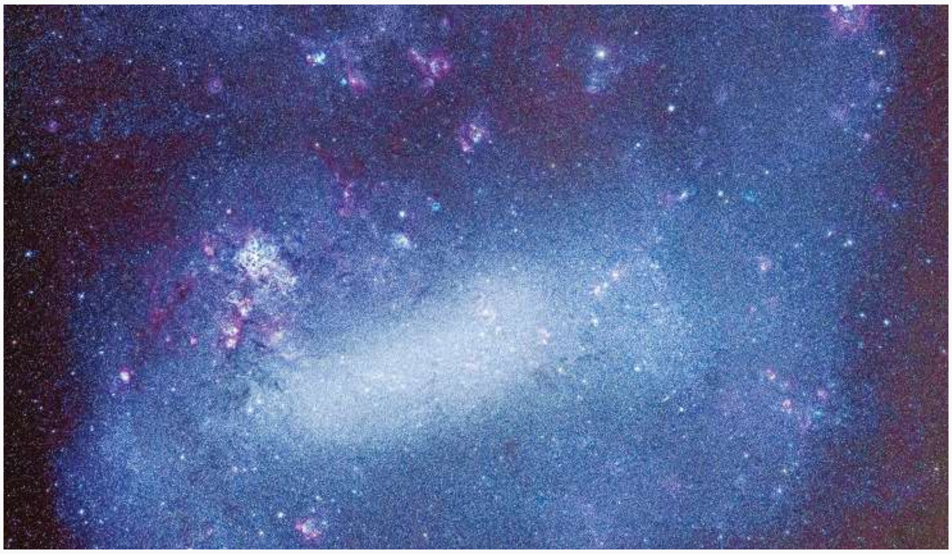
Alan Dyer

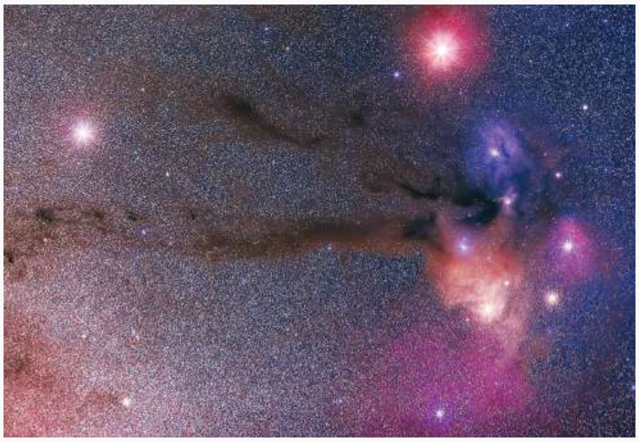
Location: Alberta, Canada

Telescope: Borg 77mm f/4 Astrograph

"While my home in rural Alberta in Canada presents fine opportunities for photographing the night sky, I love heading south as often as I can to visit sites below the equator to take in the wonders of the Southern Hemisphere sky. Only from 'down under' can you get the best views of the Magellanic Clouds and southern Milky Way sights such as the Carina Nebula.

"To capture the southern spectacles, in April 2016 I spent two weeks under mostly clear night skies near Coonabarabran, New South Wales, Australia, billed as the 'astronomy capital' of the country. Most nights were perfect for astronomy – clear, dry and mild, with no wind, bugs or dew. It was heaven on Earth for stargazing, under the finest skies you'll find anywhere."

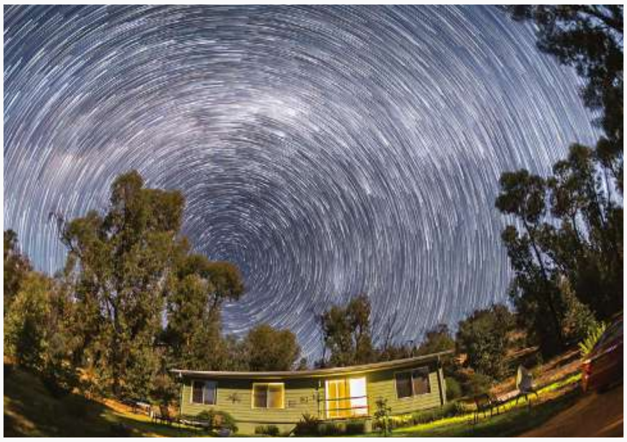




Above: The Large Magellanic Cloud

Left: Saturn and Mars in Scorpius

Right: Star trails over Tibuc Gardens Cottage, New South Wales, Australia



Margaret Dixon

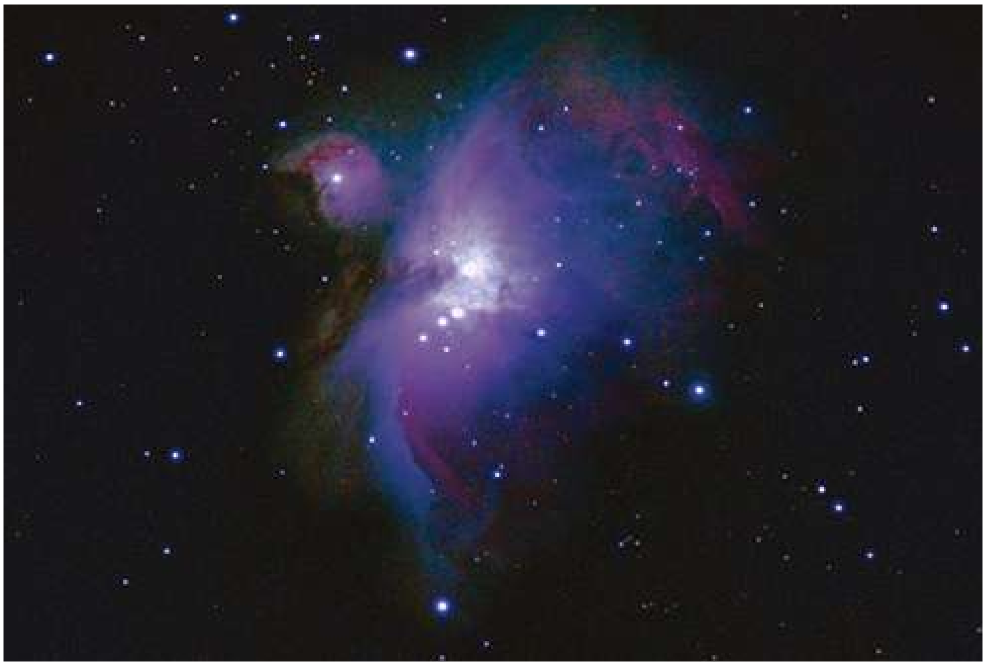
Location: County Durham, UK

Telescope: Celestron 102 GT

"I took my initial tentative steps into astrophotography when I captured my first image of Jupiter in 2012. November the following year I rather ambitiously imaged the Orion Nebula (M42). This shot was taken with a Canon 600D DSLR camera at prime focus mounted to a Celestron 102 GT refractor telescope, and 60 ten-second images were stacked using DeepSkyStacker software. I also added in 20 dark frames.

"I believe that this image shows what is possible from a back garden in a light-polluted town with a bit of perseverance, along with trial and error and loads of enthusiasm."

Right: Orion Nebula (Messier 42)



Celestron AstroMaster 102AZ

Designed for celestial and terrestrial viewing, this refractor is suitable for beginners on a budget

Telescope advice

Cost: £252 (approx. $339.19)
From: Amazon
Type: Refractor
Aperture: 4.0"
Focal length: 26"

Best for...

- Beginners
- Small budgets
- Planetary viewing
- Lunar viewing
- Bright deep-sky objects

Celestron's AstroMaster 102AZ is designed for both celestial and terrestrial viewing, so if you're a fan of observing wildlife and mountain ranges as well as the night sky, then instruments of this calibre are a worthy investment. Also, with its low price, and with everything needed to start observing supplied – including a StarPointer, steel-tube tripod and 20mm and 10mm eyepieces that supply magnifications of 33x and 66x, as well as TheSkyX astronomy software – this scope won't create much of a dent in your bank balance. Relatively portable and supplied with an alt-azimuth mount, the AstroMaster 102AZ promotes ease of use as well as minimum fuss, making it ideal for those who are just breaking into the hobby of astronomy.

Our first impression is that the build of this new addition to the AstroMaster range is exquisite. While we did note glue residue on the tube, the quality of this refractor lives up to Celestron's usual standards, and we very much enjoyed the tube's beautiful metallic-blue finish as well as the pop of orange on the Vixen-style dovetail and the mount – features that allow it to stand out from the crowd. The twist-clutch handle is very well made and screws into the mount tightly, allowing the telescope to track objects by steering.

Building the AstroMaster 102AZ is very intuitive. While instructions are supplied, we didn't feel the need to refer to them, with each of the telescope's components slotting into place with ease. A permanently mounted StarPointer takes the fuss out of calibrating the telescope session after session if it gets knocked out of place – an excellent feature that makes setting up and observing the night sky easier. The star diagonal does the job in holding the eyepieces, but as it is made of plastic it is quite flimsy. The rugged preassembled tripod comes with an accessory tray which is a bit of a challenge to fit.

Being a light instrument, we headed over to a patch of grass for extra stability during our observations. The supplied diagonal and the eyepieces fit the entire set-up nicely. However, if you're looking to substitute these with accessories made of a much more robust material then you'll find that there are balancing issues. We discovered that the view 'sagged' when we located Jupiter, which shone at a stunning magnitude of -2.5, in our field of view. Sticking to the supplied accessories, however, we found that the mount locked into place sufficiently.

With Jupiter within our field of view, the king of the Solar System showed up as a bright disc with its four Galilean moons – Io, Europa, Ganymede and Callisto – appearing as bright points of light to the sides. While we could make out Jupiter's bands with the AstroMaster 102AZ, an 80A medium blue filter enhanced them beautifully – a sight that's sure to impress those just getting into astronomy. Colour fringing, also known as chromatic aberration, was also minimal.

While we waited for Saturn and Mars to rise above the south to southeastern horizon, we tested the refractor's mettle on deep-sky objects such as the face-on spiral the Pinwheel Galaxy (M101) in the constellation of Ursa Major and slewed across to the

Left: The refractor employs a rack-and-pinion focuser for sharp views

CELESTRON
AstroMaster™102

Left: Made of steel, the tripod is well made and is well suited for use on grass for extra stability

Below: The AstroMaster 102AZ is supplied with 20mm and 10mm eyepieces for magnifications of 33x and 66x

> "THE SUPPLIED DIAGONAL AND THE EYEPIECES FIT THE ENTIRE SET-UP NICELY"

barred spiral M95 in Leo. Views of these galaxies were quite small. However, we were able to get a rich view of the Pleiades (M45) open star cluster in the constellation of Taurus before it sunk towards the horizon as the evening wore on.

Waiting until the small hours of the morning, we looked towards the southern horizon to capture Saturn and Mars. The Red Planet appeared as a small, pink disc, while Saturn's rings were unmistakable through the eyepiece. Further on into the morning and with a waning crescent Moon, an impressively clear, high-definition view of the Moon's surface was visible through the refractor.

Built for terrestrial views as well as celestial, we took the opportunity to observe a wood pigeon in a tree a few hundred metres away. Views were clear, boasting the scope's dual uses. With its ease of use the 102AZ is ideal for those looking to get started in astronomy, as well those who want an instrument built for a multitude of purposes – from observing planets to mountain peaks.

RON 10mm
ESTRON 20mm

In the shops

The latest books, apps, software, tech and accessories for space and astronomy fans alike

Vixen
POLARIE
Vixen

Sky Tracker

Vixen Polarie Star Tracker

Cost: £356.00 / $399.99
From: Rother Valley Optics / Vixen Optics
If you're an astrophotographer that gravitates towards a DSLR camera for wide-angle night-sky shots rather than a CMOS or CCD for deep-sky and planetary viewing, the Vixen Polarie is a very rewarding purchase for capturing the dusty trail of the Milky Way and other large-field shots, with no need to worry about Earth's rotation blurring imagery of the heavens. The Star Tracker can be used in both the Northern and Southern Hemispheres. We enjoyed the design of the Polarie's outer casing, which featured the Plough, or Big Dipper, on an extremely well-manufactured case.

The Vixen Polarie is powered by two AA batteries, which allowed it to operate for roughly two hours and provided non-restricted use. Sadly it didn't come with a cable, which meant that we had to carry a large number of batteries to prevent the tracker from running out of power during a full night of astronomical observation and imaging.

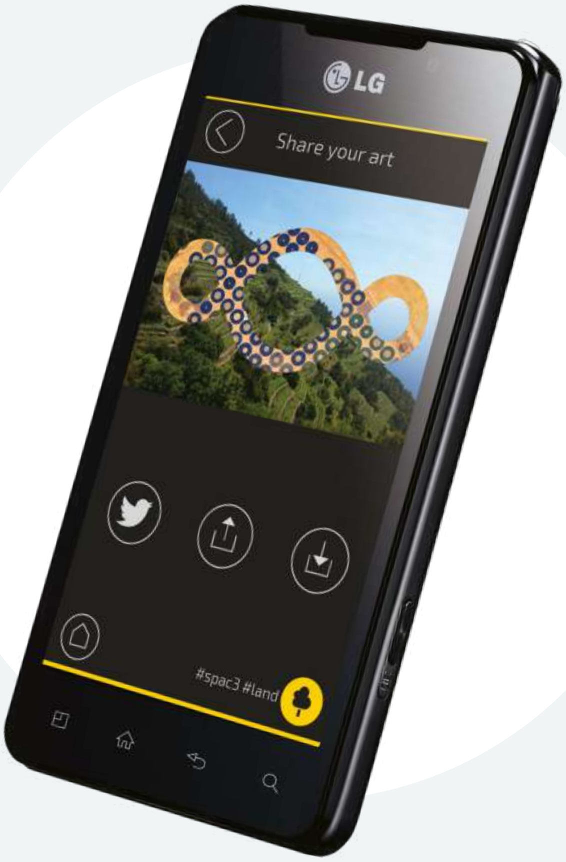
The Star Tracker held a Canon EOS 70D with no problems at all, and we found the integrated compass to be extremely useful.

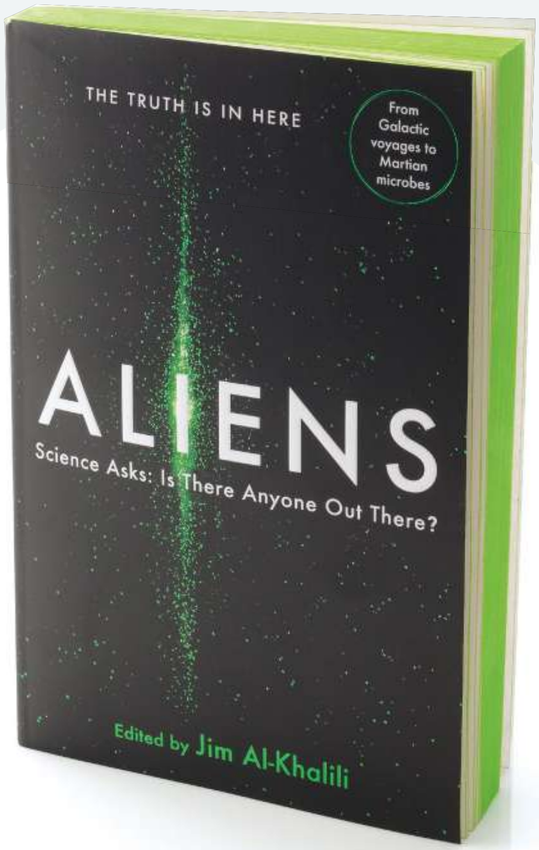
App

SPAC3

Cost: Free
From: Google Play
The SPAC3 mobile app was created to inspire, share and encourage the preservation of Earth, which is something everyone can get on board with. This collaborative effort from the European Space Agency (ESA), the Italian Space Agency (ASI), Cittadellarte - Fondazione Pistoletto and RAM radioartemobile has set out to raise awareness of global issues across different social media platforms. They are doing this by combining images taken by the ESA astronaut Paolo Nespoli - who has flown in a Space Shuttle and stayed on the International Space Station - with photos from your own smartphone photo library to create some fantastic pictures with a positive purpose.

The app specifies which of the six areas the user wishes to explore: Land, Food, Water, Health, Climate or Transformation. The six goals collectively cover the aims set out by the United Nations for the 2030 agenda to improve the planet we call home with sustainable development. The two chosen images will be merged together along with the symbol for the 'Third Paradise', which presents a strong message of togetherness. Once the images are shared on social media with the tag '#SPAC3', they will become part of a huge interactive mosaic image on the website **spac3.cloud**.

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From Galactic voyages to Martian microbes
ALIENS
Science Asks: Is There Anyone Out There?
Edited by Jim Al-Khalili

Book

Aliens: Science Asks: Is There Anyone Out There?

Cost: £7.99 / $8.82
From: Amazon

This addresses one of the biggest questions known to humankind: are we alone in the universe? Edited by professor of theoretical physics, broadcaster and author Jim Al-Khalili, *Aliens* covers every aspect of our hunt for alien life, what other life forms on other planets may be like and how extraterrestrials could behave if we were ever to make contact. If you're keen to know more about the Search for Extraterrestrial Intelligence (SETI) and want to get up to speed on the latest research, then this book is certainly worth a read.

Divided into 20 chapters written by experts at the forefront of research, including Martin Rees, Adam Rutherford and Ian Stewart, *Aliens* is an engaging piece of literature, changing pace in such a way, thanks to its vibrant choice of authors, that we were unable to put it down. It's quite easy for some authors to get carried away with claims of providing answers to some of the universe's biggest mysteries. However, this book provides an even-handed, honest and balanced view, providing what we really do know about other life forms on worlds outside our Solar System. While it may be considered to be a bold move to some readers, we enjoyed the neuroscience behind alien abductions - something that many authors of popular science books tend to skirt around when writing books in this genre.

Binoculars

Oregon Observation 11x70

Cost: £109.00 (approx. $149.00)
From: Opticron

Budding astronomers are often recommended to start out with a good-quality pair of 10x50 binoculars when they make their first tentative steps in exploring the night sky. However, we think these 11x70s are a good alternative.

We were very impressed when we put them to work - especially for the price. The rubber casing protects the optical system and makes them easy to hold. Personally, our arms began to shake after holding them up for about three minutes, so for a steadier view we attached them to a tripod - something that's fairly easy to do thanks to their versatile build.

The 70mm objective lenses are multi-coated, and combined with BAK4 Porro prisms provided pleasing views of craters on the lunar surface when we turned them skyward. The eye relief is exquisite, and there was only a hint of colour fringing along the Moon's limb and around brighter stars.

15x70
Field 4.4°
BAK-4 Fully Multi-Coated

Planetarium

Universe2go

Cost: £49.90 / $59.00
From: universe2go.com

Similar to a virtual-reality headset, Universe2go features a compartment where you're able to slot your phone, which should be preloaded with the Universe2go app. Using your phone's gyroscope and GPS, the headset 'knows' which area of the sky you're looking at in real time. The app also has the capability of placing a target in your field of view, which guides you in aiming your sights towards specific night-sky objects. Locking onto a target provides a small pop-up window that provides fast facts on the object. Locking onto constellations and objects for a few seconds starts up audio explanations on what you're observing – ideal features that make learning your way around the night sky a breeze.

Universe2go offers different viewing modes that encompass observing for beginners and experts, and it also explores the mythology behind the names of the constellations, planets and deep-space objects. You can still use the app without the headset, but this defeats the object of having a hands-free observing experience. We enjoyed the ability to use head movements to flick through the app menu, but found that it took quite a bit of getting used to before we could comfortably switch it in and out of different modes.

Filters

Optolong Venus-U & UHC filters

Cost: From £41.00 / $55.00
From: Optolong

If there's one thing keen observers of the night sky should own – after a telescope or binoculars, of course – it's a set of filters for the optimum observing experience. Using a selection of filters from a range of manufacturers, we've discovered that it's difficult to go wrong.

On trying out the Optolong filters, we found they are a cut above the rest, from their build through to how they fare during observations. These filters are expensive, but if you're looking for crystal-clear, enhanced views, Optolong filters are a worthy purchase. Venus was visible during our observing session, allowing us to put the Venus-U filter to the test. Without filters, the second planet from the Sun was so bright that it was difficult to see any detail on its disc. Turning the telescope to the planet with the filter attached, we quickly appreciated the change in contrast. Through the Optolong filter it was extremely easy to pick out details such as subtleties on the planet's cloud cover, along with a clear, obvious view of its phase. The UHC filter was just as impressive, enhancing our views of a selection of deep-sky targets – in particular the Orion Nebula – effortlessly.

OPTOLONG UHC
OPTOLONG Venus-U
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All About Space

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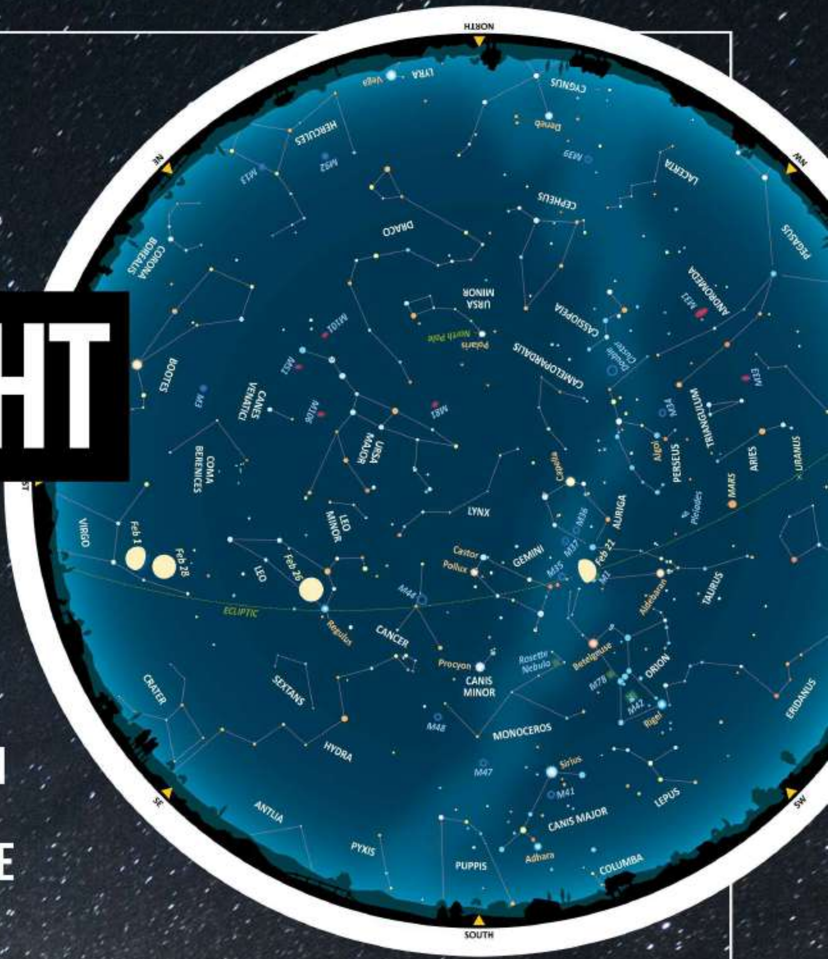
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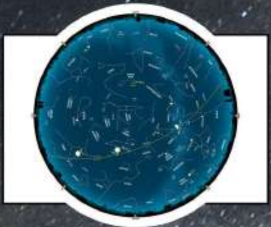
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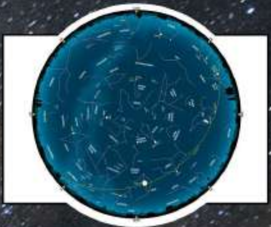
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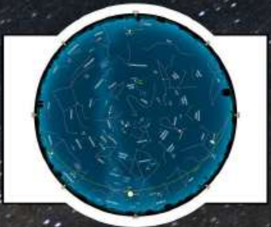
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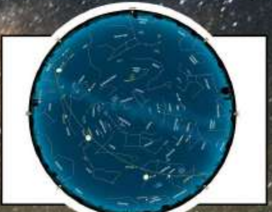
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Valeri Polyakov

This cosmonaut holds the record for the longest single stay in space

Polyakov is 78 years old, showing that his time in space hasn't affected his longevity here on Earth

Source: Wikipedia Commons © Mil.ru

Valeri Polyakov adapted well to life in space. Then again, the cosmonaut spent more than enough time away from our planet to make it feel like a second home, with not one but two lengthy stays in low-Earth orbit.

The first came in 1988 when he resided on the Soviet Union's Mir space station for 240 days. He arrived there after launching on board Soyuz TM-6 as a doctor-cosmonaut on 29 August 1988 and ventured back on TM-7 in April 1989 after conducting many medical experiments.

But even that paled in comparison to his mammoth stint five years later. Having been on board Mir from 8 January 1994 to 22 March 1995, he set the record for the longest single stay in space - a staggering 437 days and 18 hours. Those 14 months have never been beaten since.

Polyakov's 22-month combined stint was all the more remarkable given that the labyrinth that was the Mir space station remained active for just 15 years and had humans on board for all except two-and-a-half years. Lengthy stays were actually commonplace for cosmonauts, and yet such endurance was truly heroic.

His second stay in particular enabled Russian researchers to study the effects of long-duration spaceflight on the human body, particularly the mind. In that sense, it didn't seem to matter that Polyakov spent more time helping to service the failure-prone space station than experimenting. His key aim was, in effect, to keep going, and he did so by wearing a pressure suit, which would push fluids downwards, and undergoing a strict fitness regimen.

Whether or not it helped that cosmonauts were allowed the odd tipple here and there is another matter in terms of seeing such long stays through to the end. Polyakov was allowed small amounts of cognac and vodka, and such pleasures were enjoyed to such a degree that cosmonauts would bemoan how dry the ISS was when it began hosting expeditions in 2001.

So what drove Polyakov? Born Valeri Korshunov on 27 April 1942 in Tula, some 193 kilometres (120 miles) south of Moscow, Polyakov - who changed his name 15 years later when he was adopted by his stepfather - is said to have had an interest in space from a very early age.

He joined the Institute of Biomedical Problems in Moscow in 1971, specialising in astronautics medicine, and he became a cosmonaut trainee the following year, graduating with a candidate of medical sciences degree in 1976.

But he also possessed qualities that simply cannot be taught. As if to prove that the lengthy second spell in space had not adversely affected him, he left the Soyuz TM-20 capsule which had carried him back to Earth and walked - unsteadily, it has to be said - the short distance to a nearby chair. There he inhaled the smoke from a cigarette and drank a small brandy. NASA astronaut Norman Thagard said he looked "like he could wrestle a bear".

Polyakov was attempting to show that humans could survive microgravity long enough to endure a successful future trip to Mars. Studies had shown that his mental performance dipped in the first three weeks of his spaceflight, but that it had bounced back. He also had a dip in his first two weeks back on Earth, but in general his mental efficiency and emotional state was maintained at a high level.

His second trip was to be his last. He retired as a cosmonaut in June 1995, but he remains active, holding the position of deputy director of the Ministry of Public Health in Moscow. In that role he pursues a very special interest: medical care in long-term space missions. His mission to prove that humans can survive for long periods in space continues.

All About Space

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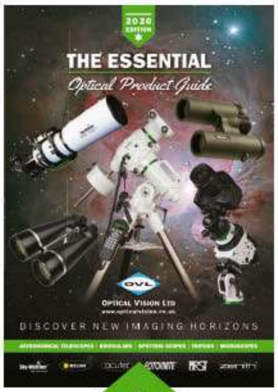

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